Course Outline
for R-304-B

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Revision ____________

Date ____________

BWR SYSTEMS

LESSON PLAN

A. REACTOR PRESSURE VESSEL AND INTERNALS

B. REFERENCES

1. BWR Systems Manual, Chapter 2.1
2. Reactor Assembly GEK 779 Volume II
3. Browns Ferry Technical Specifications
4. Reference Card File 2.1

C. OBJECTIVES

1. Description of the Reactor Vessel
2. Nomenclature, Placement and Purpose of the Reactor Vessel and Related Components
3. Flow Paths Through the Reactor Vessel
4. Basic Concepts of Brittle Fracture in Low Alloy Carbon Steels
5. Operational Limitations

D. GENERAL DESCRIPTION

1. Design Basis

   a. To contain the reactor core, reactor internals and the reactor coolant-moderator.

   b. To serve as a high integrity barrier against the leakage of radioactive materials to the drywell.

   c. To provide a floodable volume in which the reactor core can be adequately cooled in the event of a breach in the primary system external to the reactor vessel.

2. Description (Figure 1)

   a. Dimensions and Weights

      Overall height - 75' 1-15/16' - (bottom of skirt to top of center head nozzle flange - see drawing 104R935)

Inside diameter - 251"

Wall Thickness
Cylindrical Sections - 6-7/16"- plus 1/8" stainless steel overlay on the interior

Bottom head - 8-7/16"-plus 1/8" stainless steel overlay on the interior (Extra thickness is needed to compensate for the CRD housing penetrations.)

Weights

Reactor vessel without head -	624.5 Tons
Head Only	126.0 Tons
Total -	750.5 Tons

Note: The reactor vessel head is the heaviest lift for the reactor building overhead crane and is the basis for sizing of this crane. Head weight includes 30 tons which is the weight of the head studs, nuts and washers.

b. Materials

1) Base metal - low manganese - molybdenum low carbond steel alloy

2) Inside overlay - weld overlaid of austenitic stainless steel applied to all interior carbon steel surfaces of both the vessel and head.

Purpose - to cover all carbon steel surfaces to minimize corrosion which would adversely affect water clarity during refueling operations.

c. Head Attachment

1) Held on by 92 studs and nuts (more later)

d. Vessel Nozzles (Figure 1)

1) Level instrumentation and reactor vessel vent nozzle - quantity: 1

a) Purpose - provide a tap for wide range level instrumentation and a vent for non-condensible gases.

b) The vent function is used during shutdown and is primarily needed following isolation of the main steam lines. Gamma radiation from the core dissociates water into H_2 and O_2 which must be vented to permit vessel flooding and cooldown.

2) Head Spray Nozzle - Quantity: 1

a) Purpose - provide for spraying cool water from the head spray mode of the residual heat removal system to collapse steam in that area to permit vessel flooding while shutting down the plant.

3) Spare Head Nozzle - Quantity: 1

a) Purpose - Originally used for vibration measurement instrument leads connected to the jet pumps, shroud head and steam separators, and steam dryer assembly.

(1) Also used for moisture carry over measurement sensing lines to test performance of the steam separators and steam dryer assembly.

b) All the above instrumentation is usually removed during the first outage following successful completion of testing. The nozzle is then blank flanged.

4) Main Steam Nozzles - Quantity: 4

a) Purpose - to conduct dry steam out of the reactor.

b) Note that nozzles are not at 90° angles from each other. This is due to the configuration of the steam dryer (more later).

5) Instrument Nozzles - Quantity: 6

a) Purpose - provides for the sensing of reactor water level and pressure.

6) Feedwater Nozzles - Quantity: 6

a) Purpose - conducts feedwater into the reactor vessel as required to replace steam sent to the turbine in order to maintain a constant water level.

7) Core Spray Nozzles - Quantity: 2

   a) Purpose - provides for the low pressure spraying of the core in the unlikely event of a loss of coolant accident.

8) Control Rod Drive Hydraulic System Return Nozzle - Quantity: 1

   a) Purpose - returns excess water to the reactor vessel that is not used for moving or cooling the control rod drives.

9) Recirculation Suction Nozzles - Quantity: 2

   a) Purpose - provides water from the reactor to the suction of the recirculation pumps.

10) Recirculation Inlet Nozzles - Quantity: 10

   a) Purpose - routes water from the discharge of the recirculation pumps to the driving nozzles of the jet pumpts to provide the required core flow.

11) Jet Pump Instrument Nozzles - Quantity: 2

   a) Purpose - routes jet pump differential pressure flow sensing lines out of the reactor vessel.

12) Core Differential Pressure and Standby Liquid Control Nozzle - Quantity: 1

   a) Purpose - to provide for injection of sodium pentaborate to shutdown the reactor in the event of failure of the control rod drive and/or reactor protection system to scram the plant.

      To provide instrumentation taps for measurement of reactor core differential pressure.

      Also provides a pressure reference for determining jet pump flow.

13) Bottom Head Drain - Quantity: 1

   a) Purpose - to provide for draining of the vessel during construction testing and flushing.

b) Located at the lowest point of the reactor vessel to assure good crud removal.

c) Connects to the Reactor Water Cleanup system to provide a continual flow of water out of the bottom head region to prevent the accumulation of cold water.

Cold water comes from the cooling water in flow in the control rod drives and can build up in the bottom head regiona during low core flow conditions.

e. Refueling Bellows Skirt (Figure 1)

1) Purpose

a) Provides a weld attachment for the refueling bulkhead bellows.

b) The bulkhead and bellows combination provide a water tight seal at the flange area of the reactor vessel to permit flooding of the reactor cavity to permit transfer of spent fuel out of the vessel.

2) Bellows and bulkhead will be covered in detail in the Fuel Pool Cooling System presentation.

f. Insulation Supports (Figure 1)

1) Welded rings provided at various locations to support the vessel metallic insulation.

g. Thermocouple Mounting Pads (Figure 1)

1) Located at several locations on the vessel proper and support skirt to provide for monitoring of temperature of the reactor vessel. (Will be discussed in detail in the Reactor Vessel Instrumentation presentation.)

h. Vessel Construction (Figures 1 and 2)

1) Shell Sections (Figure 1) - 4 total cylindrical shell courses, each shell course consisting of 2 or more rolled plate sections welded together at vertical seams.

2) Shell Course No. 3 (Figure 2) - This particular shell course has 5 vertical welds, all located away from the nozzles.

3) Top Head (Figure 2)

Consists of: "Dollar" piece on top that accommodates the 3 head nozzles. Tapered sections form the remainder of the spherical head. Flange section is two semi-circular pieces welded together.

4) Bottom Head (Figure 2)

Approximately the same design as used for the top head. Note that all welds are outside the area where the CRD and incore housing penetrations are located.

i. Reactor Vessel Support (Figures 3 and 4)

1) Vertical Support (Figure 3)

a) Purpose - to vertically support the entire weight of the vessel, internals, fuel and moderator.

b) Consists of the following:

Vessel Support Skirt (Welded to Bottom Head)
Ring Girder
Sole Plate
Concrete Founded on Bedrock

2) Lateral Support (Figures 3 and 4)

a) Purpose - to provide lateral support for the vessel.

Designed to accommodate both seismic forces and jet forces resulting from the breakage of any pipe attached to the reactor vessel (e.g., a main steam line).

b) Vessel to Biological Shield Stabilizers

4 tie down points are provided on the reactor vessel at 90° angles from each other.

8 tensioned spring washer stabilizers tie the reactor vessel to the biological shield.

These are basically spring loaded turnbuckles. The tension is adjusted following stabilizer installation by rotating the adjusting nut.

c) Biological Shield to Containment Stabilizer

8 pairs of stabilizers located at 45° angles from each other.

Consists of 10" diameter pipes welded to top of biological shield and bolted to fittings on the containment wall.

Gibs between the exterior of the containment and the reactor building accommodate vertical differential expansion of the drywell and reactor building concrete.

Lateral support is provided in compression only, so that no tension forces are applied that will pull the containment inward.

E. COMPONENT DESCRIPTION (Figure 5)

1. Review

Briefly go over Figure 5 and review the location and configuration of the major reactor vessel internal components.

2. Order of Discussion

The reactor vessel internals discussed below will be covered in the order in which they were installed in the reactor vessel during plant construction.

3. Baffle Plate (Figure 5 and Drawing 104R935)

a. Also known as diffuser seal ring and shroud support plate.

b. Purpose

1) To provide a mounting surface for the jet pump diffuser.

2) To separate the recirculating suction area (downcomer area) from the core inlet plenum area (below core plate area).

c. Installation

1) Installed in the factory prior to shipment to the field.

2) Welded to the vessel wall.

3) Supported by 6 column members welded directly to the vessel bottom head (See 104R935, Sheet 1)

4) The support columns support the weight of:

Jet Pumps
Shroud and Core Spray Sparger
Core Plate
Top Guide
Peripheral Fuel Bundles

5) Note: There are 2 access holes in the core plate, 180° from each other. (See Drawing 104R935, Sheet 2)

These provide access to the below core plate area during construction.

Upon completion of construction, these access holes are welded shut using cover plates.

4. Jet Pumps (Figures 5, 6 and Drawing 104R935)

a. Purpose

To provide forced flow of coolant-moderator through the reactor to yield higher reactor power output than would be possible with natural circulation.

b. Description (Figure 6)

10 jet pump assemblies each consisting of the following:

1 Inlet Riser and Thermal Sleeve
1 Transition Piece Welded to Top of Inlet Riser
2 Nozzles
2 Mixing Sections
1 Bracket and Restrainer Gate Assembly
2 Diffuser Sections Having a 19" Inside Diameter at the Bottom

c. Installation

1) Riser Assembly

a) Thermal Sleeve

On end of riser, is welded into the nozzle at the outer end (pipe attachment end). (See Drawing 104R935, Sheet 1)

b) Purpose of Thermal Sleeve

To prevent overstressing the reactor vessel nozzle due to differences in temperature between inlet water and vessel wall and nozzle temperatures.

c) Worst Case Conditions

(1) Normal Operation

Operation of Shutdown Cooling during Plant Cooldown.

(2) Emergency Operation

Injection of cold water from the Low Pressure Coolant Injection System.

d) Riser Brace Arms (Drawing 104R935)

(1) Purpose

To support the upper end of the riser and provide for the vertical differential expansion between the riser and reactor vessel during heatup and cooldown. (See Drawing 104R935, Sheet 1 and 2)

To provide adequate restraint to accommodate riser vibration which can occur under certain modes of recirculation system operation.

(2) Two Sets of Brace Arms

Tuning Fork Type
Single Bar Type

(3) Tuning Fork Type

Welded to vessel wall and bracket which is welded to riser.

(4) Single Bar Type

Added for additional restraint of riser. (Newer plants have a different design riser brace arm system.)

Located just below the tuning fork brace arms.

e) Reason for Risers

Used to permit lowering of the Recirculation inlet nozzles to get them out of the active core region so that they don't receive any significant fast neutron exposure which could change the mechanical properties of the materials.

2) Diffusers

a) Adaptor

(1) 6" high, 19" diameter adaptor is first welded to the baffle plate.

(2) This is done to make the welding and precise alignment of the diffusers easier.

(3) The diffusers are then aligned and welded to the diffuser adaptors.

(4) Upper end of diffuser has 4 guide vanes and a slip fit joint to accommodate the mixer sections.

(5) Guide vanes make it easy to change out mixer section from the reactor flange area.

3) Mixer Sections

a) Slips into upper end of diffusers.

b) Restrained at midpoint by the bracket and restrainer gate assembly. (See Drawing 104R935, Sheet 2)

c) Each slide of the bracket assembly consists of:

2 restrainer gates that can be unbolted to swing outward to permit installation/removal of the mixing section.

2 adjustable bolts 120° from each other that are set to provide the proper lateral restraint of the mixer section.

A wedge assembly that is spring loaded in the downward direction holds the mixer section against the above 2 adjustment bolts.

(more on purpose of this assembly later.)

d) A "D" handle is provided on the wedge assembly so that it can be lifted to permit closing of the restrainer gates with the mixing assembly in place.

4) Nozzles

a) Nozzles change the direction of the driving flow 180°. The nozzle end has the flared opening to accommodate the plenum water as an integral part of the nozzle.

b) Bolted down at upper end to the transition piece.

c) The lower end is secured to the upper cylindrical shaped mixing section by a clamp.

d. Purpose of having a slip fit at the diffuser and mixer sections.

1) The inlet riser enters the reactor vessel at a higher elevation than the bottom of the diffusers which is permanently welded to the shroud support (baffle plate).

2) There will be different vertical growths during reactor heatup and cooldown of:

Stainless Steel Riser Assembly
Stainless Steel Diffuser Assembly (Different Length than Riser)
Carbon Steel Reactor Vessel

3) Therefore an expansion joint is required to accommodate the net differential expansion of these components.

e. Purpose of having a bracket and restrainer gate assembly:

1) A phenomenon known as fretting corrosion has been observed in stainless steel in reactor environments.

2) Fretting corrosion is primarily vibration induced.

3) A bracket and restrainer gate assembly is employed to assure there is no vibration between the mixer to diffuser slip fit.

4) The combination of the bracket, restrainer gates, wedges, etc., assures maximum stiffness of the mixer section and prevents any vibration from occurring and hence fretting corrosion does not occur.

f. Flow Paths and Basic Operation

1) Driving water enters the inlet riser, the transition piece, and its direction is turned downward by the nozzles.

2) The nozzles increase the velocity of the driving water and at the same time lower its pressure.

3) The lower pressure in the upper end of the mixing section draws the water in the plenum and the two flows are carried downward together and mixed in the mixing section.

4) The diffuser section slows the flow and thereby increases the pressure of the fluid.

5) The higher pressure water exits the lower end of the jet pump and into the lower plenum where it then passes up through the core.

g. Jet Pump Principles of Operation

Will be covered in more detail during the Recirculation System presentation.

h. Jet Pump Height Consideration

See discussion under G.2. Core Floodability

i. Jet Pump Flow Sensing Lines (Drawing 104R935, Sheet 2)

1) Purpose

To provide a mechanism for measuring flow in each jet pump.

2) Every jet pump has an instrument line taped into the upper end of the diffuser.

3) Ten lines (all lines for one recirculation loop) are fed out of the vessel through a single penetration.

4) Other loop has identical configuration.

5. Core Shroud (Figure 7 and Drawing 104R935)

a. Purpose

1) Divides the downcomer flow from the core flow.

2) Provides lateral support for the core plate and top guide and hence lateral support for the fuel bundles.

Note: Vertical support of the top guide, core plate and all fuel is provided basically by the vessel bottom head and vessel support skirt through the shroud.

b. Description

1) A 2" thick stainless steel cylindrical assembly welded in the field to the upper lip of the baffle plate (See Drawing 104R935, Sheet 1) extending up beyond the top of the jet pumps and fuel.

2) Includes the core spray spargers

3) Installed upon completion of jet pump installation

c. Closure Surface

1) Upper surface is machined to provide a leak tight fit with the shroud head.

2) 48 sets of lugs provided for securing shroud head to the shroud.

3) 2 alignment brackets, each having 2 holes, serve the following purposes.

a) Inner Hole

Accommodates short alignment pin on the shroud head thereby assuring proper shroud head azimuth alignment with the shroud prior to boltup.

b) Outer Hole

Provides a slip fit restraint for the lower end of the two shroud head guide rods (See Drawing 104R935)

c) The upper end of the shroud head guide rod is secured by a bracket welded to the side of the reactor vessel.

d) The purpose of the shroud head guide rods is to aid in guiding the shroud head into the proper place on top of the shroud to assure proper boltup.

6. Core Spray Spargers (Figures 7 & 8)

a. Purpose

To provide 2 redundant spray networks that will yield a spray pattern covering the entire top of the core in the event of a loss of coolant accident.

b. Description

1) Consists of spargers with nozzles and the supply piping.

2) Spargers are permanently mounted inside the upper part of the shroud.

3) 2 elevations of spray headers.

4) Each of the 2 eveltions will provide 100% of design flow and spray coverage.

5) Each elevation consists of 2 individual 180° sections.

6) Each spray header is secured to the shroud inner wall by several brackets which weld only to the shroud.

This leaves the piping free to contract when the Core Spray system injects cold water into the hot reactor vessel during accident conditions.

7) The nozzle angles are aligned during preoperational testing to assure proper spray pattern and are then tack welded in place.

8) The supply piping is arranged as shown on Figure 8 to accommodate piping contraction during injection of cold water into the hot reactor vessel.

7. Core Plate (104R935, Sheet 1 and Figure 9)

   a. Purpose

      1) Provides vertical and lateral support for the 24 peripheral fuel bundles.

      2) Provides lateral support for the control rod guides tubes and hence lateral support for the fuel support castings and fuel bundles.

      3) Note: Vertical support of all fuel except the peripheral fuel bundles is provided by the fuel support castings, control rod guide tubes and the bottom head of the reactor vessel.

      4) Acts as a partition to force the majority of the moderator-coolant up through the fuel bundles rather than outside them.

   b. Description

      1) Location

         Bolted to the lower shoulder of the shroud.

      2) Consists of:

         Thin Stainless Steel Top Plate
         Stiffener Plate Members Below the Top Plate
         Tie Rods to Cross Brace the Stiffener Members
         185 Control Rod Guide Tube Holes
         185 Alignment Pins for Assuring Proper Control Rod Guide Tube and Fuel Support Casting Orientation
         24 Peripheral Fuel Support Pieces
         55 Incore Guide Tube Holes
         12 Guide Sleeves for SRM & IRM Incore Guide Tubes (Note: These guide sleeves are only provided to provide continuity of the cross-tie rods which happen to run through the SRM and IRM locations.)
         14 Neutron Source Location Holes
         Bolts to Hold the Core Plate to the Shroud

   c. Installation

1) Sequence

Is installed in the field following shroud installation.

2) Alignment

Aligned using 4 alignment pads welded to step in core shroud so that centers of the control rod guide tubes are directly over the center of their respective control rod drive housing penetrations in the reactor bottom head.

8. Top Guide (Drawing 104R935 and Figure 10)

a. Purpose

1) Provides lateral support for the upper end of all fuel bundles.

2) Provides lateral support for upper end of the neutron monitoring instrument assemblies (Source Range, Intermediate Range and Local Power Range Monitors).

3) Provides lateral support for upper end of the neutron sources.

b. Description

1) Box-like structure of stainless steel plate set in a step at the top end of the shroud.

2) Each central box opening accommodates 4 fuel bundles and one control rod. (This is the definition of a fuel cell.)

3) There are 24 openings near the outside, each of which accommodate one of the 24 peripheral fuel bundles.

4) Shallow notches are cut in the tops of the cross members. This was to accommodate poison curtains which are no longer used.

5) Each nuclear instrument assembly and source holder is supported by a cutout on the bottom side of the core plate at the junction of the cross member (See Figure 10).

9. Incore Housings and Guide Tubes (Drawing 104R935)

a. Definitions

Incore Housing:	That portion starting at the weld (shown on Drawing 104R935, Sheet 1, coordinates D-27 and ending at the flange surface at coordinates D-32.
Incore Guide Tube:	That portion starting at the weld mentioned above and terminating at the core plate.

b. Purpose:

1) Is an extension of the reactor vessel which provides for mounting of the incore nuclear instrumentation (Source Range Monitors, Intermediate Range Monitors and Local Power Range Monitors) and convenient bottom leadout of their electrical cables and mechanical drives.

2) To prevent jet pump flow (core flow) impingement on the nuclear instrumentation assemblies in the below core plate area and thereby eliminate possible vibration damage to these assemblies.

c. Description

1) Housing and guide tube are 2" OD stainless steel pipe.

Housing has bolting flange at bottom end.

2) Guide tube extends upward and terminates in a slip fit in the core plate 0.5" below the top surface of the core plate.

3) Quantity:

43 for Local Power Range Monitors (LPRM)
8 for Intermediate Range Monitors (IRM)
4 for Source Range Monitors (SRM)
—
55 Total

4) Assemblies are located in the water gap between fuel cells (See Drawing 104R935)

5) SRM and IRM Dry Tubes and LPRM assemblies are loaded into the guide tubes from the top of the reactor.

The nuclear instrumentation assemblies extend upward from the core plate and are secured by the under side of the top guide.

SRM and IRM detector are installed from below the vessel.

d. Installation

1) Incore housings and guide tubes are provided to the field as separate units.

Reason: There is inadequate clearance under the reactor vessel to accommodate the overall length if they were fabricated as a one piece unit.

2) Housings are aligned with their respective opening in the core plate and welded directly to the reactor vessel bottom head (See Drawing 104R935 for vessel penetration details).

3) Incore guide tubes are welded to the housings upon completion of installation of all incore housings and control rod drive housings.

4) Cross Bracing

90° box-like cross bracing is installed thereby tying all the incore guide tubes together (See Drawing 104R935)

Bracing is to eliminate vibration of the guide tubes and nuclear instrumentation assemblies.

5) Cooling Holes

4 cooling holes 1/4" diameter are drilled at 90° from each other near the lower end of the guide tubes used by LPRM instruments.

Purpose: To provide a cooling path for the nuclear instrumentation assemblies.

10. Control Rod Drive Housings (Drawing 104R935)

a. Purpose

1) Is an extension of the reactor vessel for mounting of the control rod drive.

2) Provides both vertical and lateral support for the drives.

3) Transmits weight of the fuel, fuel support casting and control rod drive guide tube to the reactor bottom head for support.

b. Description

1) 14+ feet long, 5" ID stainless steel

2) Flange at Bottom is for:

a) Permanent attachment of the CRD hydraulic system insert and withdraw lines.

b) Bolting of control rod drive mechanism.

3) Keyway at the flange end is provided for locking the control rod drive thermal sleeve and preventing it from rotating.

c. Installation

1) Housings are raised into position from below the reactor vessel.

2) Housings are optically aligned through their respective core plate openings (hence housing installation cannot begin until core plate is installed).

3) Welded to an Inconel Stub Tube

Stub tube allows easier welding and alignment of the housings than would be possible if housings were to be welded to the reactor directly.

4) Top surface of the housings are all at the same elevation.

11. Control Rod Guide Tube (Drawing 104R935 and Figures 12, 13 and 14)

a. Purpose

1) To provide lateral support for the control rod blade velocity limiter.

2) To transmit the weight of the fuel and fuel support castings to the reactor bottom head via the control rod drive housing.

b. Description (Figure 13)

1) 11" diameter by 13+ feet long thin wall cylinder

2) Top has four 3" diameter holes to pass the core flow from the below core plate area into the fuel bundle.

3) Bottom end is machined to mate with the CRD housing.

c. Installation (Figure 14)

1) Guide tube is lowered through the core plate from above, aligned with the core plate alignment pin, and set on its CRD housing.

2) CRD thermal sleeve is inserted upward into the CRD housing from below the reactor, engaged with the guide tube and rotated to lock the guide tube in place.

3) A key is inserted in the lower end of the CRD housing to prevent the thermal sleeve from rotating and releasing the guide tube.

12. Orificed Fuel Support (Figure 15)

a. Purpose

1) Provide lateral alignment for bottom end of fuel assemblies.

2) Transmit weight of fuel to the control rod guide tube and down to the reactor bottom head.

Note: The weight of the fuel is <u>not</u> carried by the core plate.

3) Through orifices, control the amount of flow to each fuel bundle.

b. Description (Figure 15)

1) A 4 Lobe Stainless Steel Casting

2) Supports 4 Fuel Bundles

3) Individual Orifices and Flow Paths for Each Fuel Bundle

c. Installation

1) Slip fits into the control rod guide tube.

2) Alignment dog fits over pin on core plate to assure that orifices in fuel support are in line with openings in the control rod guide tube.

13. Assembled Drive Line

See Figure 16 for overall configuration of the completed installation.

14. Peripheral Fuel Support (Figure 17)

a. Purpose

1) Provide vertical and lateral support to the 24 individual peripheral fuel bundles that are not part of complete 4 bundle fuel cells.

2) To properly orifice the flow to the peripheral bundles.

b. Description

1) Body of support piece is permanently fixed into the core plate.

2) Separate removable orifice can be changed out with special handling tool from the reactor flange area if necessary.

15. Orificing of Flow Through Fuel Bundles

a. Why Orifice

1) Assume a core that has no flow orificing.

2) In a BWR, as power is increased, the amount of boiling (two phase flow) within a fuel bundle increases.

3) More cooling is necessary for a higher power bundle (one with more boiling) than a lower power bundle.

4) Peripheral bundle, for example, run at approximately half the power of the central region bundles.

5) As two phase flow increases within the higher power bundles, increased resistance to flow occurs.

This would tend to reroute flow to the lower power fuel bundles thereby tending to starve the higher power bundles.

This is precisely what you don't want to happen.

6) By providing flow orificing in the fuel support pieces, the majority of the pressure drop across the core is taken at the orifice.

7) The pressure drop across the orifice is large in comparison to the pressure drop in the fuel bundle itself and consequently, any changes in two phase flow within individual fuel bundles causes insignificant changes in flow patterns between high and lower power fuel bundles.

b. Flow Orificing (Figure 18)

1) The core is divided into 2 orificing zones.

Central Region
Peripheral Region

2) The peripheral region consists of bundles near the outside of the core that are supported on regular 4 bundle supports as well as the individual peripheral fuel supports.

3) Orifice Sizing:

Central Region	2.3" diameter
Peripheral Region	
4 Bundle Support Orifices	1.4" diameter
Peripheral Support Orifices	3-3/4" diameter holes

16. Feedwater Spargers (Drawing 104R935)

a. Purpose

To evenly distribute feedwater to the jet pumps and recirculation pump suctions in a manner such that:

1) Cold water does not impinge upon the reactor vessel walls and

2) The core flow up through the core is properly mixed and of consistent temperature.

b. Description (Drawing 104R935)

1) Six $\sim 40^{\circ}$ Spargers

2) Each has a thermal sleeve welded to the sparger and slip fits into the reactor vessel nozzle.

Thermal sleeve is needed to prevent excessive thermal stress in the feedwater nozzles which would occur if cold feedwater came into contact with the hot nozzle.

3) Two rows of holes provide for even distribution of the cold feedwater throughout the annulus.

c. Installation

1) The thermal sleeves are slip fit into their respective feedwater nozzles.

2) Both ends of each sparger are secured to brackets on the reactor vessel wall.

3) Spargers are removeable anytime in plant life.

4) Because of sparger vibration problems, the sparger thermal sleeve is often welded or presses fit into the reactor vessel.

17. Standby Liquid Control/Core Differential Pressure Piping (Figure 19)

a. Purpose

1) Inlet and distribution line for sodium pentaborate.

2) Provides for measurement of above and below core plate pressures and hence core differential pressure.

3) Provides for measurement of lower plenum (below core plate) pressure for use in jet pump flow measurement.

4) Provides input to core spray line break detection instrumentation.

b. Description

1) A pipe within a pipe.

2) Inner pipe connected to the Standby Liquid Control System and senses below core plate pressure.

3) The use of spray line break detection, core differential pressure and jet pump flow taps will be discussed in detail in later lesson plans.

c. Installation

1) Permanently Installed

18. Vessel Bottom Head Drain (Drawing 104R935)

a. Purpose

1) Drain

Functions as a low point drain during construction flushing of the reactor vessel.

2) Crud Removal

By being connected to the Cleanup System suction, a continual outflow of water is maintained to remove crud from the bottom head area and prevent its buildup and resultant radiation exposure problems to personnel in the below vessel area.

3) Cold Water Stagnation Prevention

By being connected to the Cleanup System suction, a continual outflow of water is maintained to assure that cold water (from cooling water inflow from the control rod drives) does not stratify in the bottom head area under low core flow conditions.

Any cold water accumulation in this area with the remainder of the reactor vessel hot would cool down the bottom head area.

When core flow is increased, sweeping out the cold water and replacing it with hotter water, an uncontrolled heatup occurs in the bottom head area which could over stress the stub tube and reactor vessel skirt welds.

4) Bottom Head Temperature Measurement

A thermocouple is attached to the outside of the 2" drain line. Wall thickness of the 2" pipe is a small fraction of the vessel wall thickness and a more accurate measurement of bottom head temperature can be obtained than by placing of thermocouple on the vessel wall.

b. Description

A 2" nozzle at the low point of the reactor vessel bottom head.

19. Shroud Head (Figure 20)

a. Purpose

To close off the core outlet so that all moderator and steam is forced through the steam separators.

b. Description

1) Consists of

Shroud Head
Stand Pipes
Steam Separators
Vibration Crossbracing
Tie Down Lugs
Tie Down Bolts
Bolt Support Rings

2) Assembly has to be removed for refueling.

c. Installation

1) A strong back attaches to the 4 lifting eyes.

2) Lifted by the reactor building overhead crane.

3) 2 guide rods 180° from each other secured at the upper end by brackets welded to the vessel wall and at the lower end by brackets on the upper edge of the shroud provide an easy method of remotely guiding the shroud head into place during installation.

4) 2 mating guide brackets on the shroud head (Figure 20) fit over the above 2 guide rods. This assures that the bolts and both sets of lugs are properly aligned.

5) The shroud head is attached to the shroud with long bolts that squeeze together the lugs on the shroud and shroud head (Figure 21).

6) The bolt consists of the following parts:

Inconel Bolt -
Has a "T" hook at the bottom to fit under the lugs on the shroud periphery.

Through use of the rotating dog at the top end, the bolt can be rotated a maximum of 90°.

Stainless Steel Sleeve -

Loosely fits over inconel bolt. Two built up larger diameter wear shoulders on the sleeve loose fit into the two circular bolt guide rings on the shroud head (See Figure 20). These guide rings provide lateral support only.

Bottom end has flat "T" shaped surface to mate with the top of the lugs on the periphery of the shroud head. This provides the vertical support for the bolt and prevents the sleeve from rotating.

Bottom end has a cut out slot that permits rotation of the inconel bolt 90°.

Indent in bottom of cut away accepts pin on inconel bolt and assures bolt is in position to slip between the shroud lugs when the shroud head is lowered.

· Tensioning Nut -

Threaded onto inconel bolt.

Pushes downward on the stainless steel sleeve while at the same time pulling up on the inconel bolt thus squeezing the lugs on the shroud and shroud head together.

Keeper Nut -

Spring loaded in the upward direction.

Keyed into the stainless steel sleeve to prevent rotation.

Purpose is to prevent loosening of the tensioning nut once it is tightened.

Stop Nut -

Is tack welded in place once it is adjusted to provide for the proper amount of backing off of the tensioning nut necessary to place the inconel bolt in its down and 90° rotated position.

Prevents accidental removal and droppage of the tensioning nut into the reactor vessel.

7) Once the shroud head is set in place on the shroud, the shroud head bolts are rotated 90° so that the inconel bolt head will engage the shroud lugs.

8) Tensioning nuts are torqued to 50 ft. lbs. This promotes only partial tensioning of the bolts.

9) The balance of the tensioning is provided when the moderator heats up the bolt and sleeve during plant heat up.

10) The stainless steel expands more than the inconel bolt thus squeezing the shroud and shroud head lugs together harder as the reactor temperature increases.

11) Partial tensioning through use of dis-similar metals is used to make it easier and quicker to bolt down and remove the shroud head.

d. Precautions

1) Since the shroud head bolts are tensioned only partially when the vessel is cold, the recirculation pump cannot be run at full speed during preoperational testing until the moderator temperature is >140°F.

Otherwise the shroud head will partially lift off of the shroud.

20. Steam Separators (Figure 22)

a. Purpose

To increase steam quality from 10 - 13% at core exit to at least 90%.

b. Description

1) Standpipe

Transmits steam - liquid mixture to the moisture separators.

2) Separators

a) Centrifugal Type Separator

b) Permanently Welded to Standpipes

c) Cross bracing promotes a rigid structure and prevents vibration (See Figure 20).

d) Turning vane at inlet imparts a rotation to the incoming two phase fluid.

e) More dense liquid is thrown to the outside by centrifugal force forming a continuous wall of water against the inside of the inner pipe.

f) Three stages of separation return the liquid to the downcomer area and on to the recirculation pump and jet pump suctions.

g) Steam qualities at rated power

Core Exit	10% - 13%
Separator Exit	95%

c. Moisture Carryover

1) Definition

That moisture exiting the steam separator at the top.

2) Problems with Moisture Carryover

Too much carryover to the steam dryers will overload them with a resultant decrease in steam quality exiting the reactor vessel.

Moisture carryover is minimized in order to:

a) Increase Turbine Efficiency

b) Decrease Turbine Wear

c) Minimize Radioactivity Carried Over to the Balance of Plant.

3) Water Level Effect on Carryover

a) If the water level surrounding the separators is too high, the water in the separator tends to backup with resultant moisture carryover out the top of the separator.

b) Note that on Figure 23, a very wide deviation in water level is possible before any significant carryover results.

d. Steam Carryunder (Figure 23)

1) Definition

That steam which exits the separators that is entrained in the liquid separated from the separators.

2) Where Measured

At the outlet of the separators before the colder feedwater is mixed into the separated liquid.

3) Origin of Steam Carryunder

Some steam carryunder is always present (See Figure 23).

Can become excessive due to running with the reactor water level too low.

4) Problems with Excessive Steam Carryunder

a) Recirculation Pumps

(1) Steam bubbles in liquid yield a lower density fluid than would be the case if there were no steam bubbles.

(2) A 0.2% weight percent steam carryunder means ~2% by volume.

(3) If the lower density fluid reaches the recirculation pumps, there is increased chance of pump cavitation.

(4) More pumping power will be required to pump the less dense fluid due to the necessarily increased fluid velocities and resultant frictional line losses.

b) Plant Efficiency

The plant operates less efficiently since steam that is carried under is not sent to the turbine.

c) Core Considerations

(1) Core average void content will increase slightly.

(2) Core pressure drop will be slightly increased due to higher two phase flow.

(3) Minimum critical power ratio (MCPR) will be slightly reduced.

Note: These considerations will be discussed in detail under Thermal Hydraulics. The intent here is to acquaint the student with the concept effects and control of steam carryunder.

21. Steam Dryer (Figure 24 and Drawing 104R935)

a. Purpose

1) To dry the fluid coming out of the steam separators to >99.9% quality.

2) To provide a seal between the wet steam area (steam exiting the moisture separators) and the dry steam flowing to the turbine.

b. Description (Figure 24)

1) One piece assembly with no moving parts except the hold down mechanisms.

2) Upper section consists of Peerless type steam dryers and moisture collection troughts and drain lines.

3) Upper section has sides "cut away" to permit steam flow to the main steam lines.

By placing main steam nozzles as shown rather than at 90° angles from each other, more steam dryer panels can be built into the dryer with a resultant lower overall dryer pressure drop.

4) Lower section consists of a seal skirt.

c. Steam Dryer Panels (Figure 25)

1) Type Peerless Brand Dryers - same as used in the turbine moisture separators.

2) Principle of Operation

a) Operates on centrifugal force and gravity principles.

b) Wet steam mixture rises from the steam separators through baffling, and is forced horizontally through the dryer panels.

c) The wet steam is forced to make a series of rapid changes in direction while traversing the dryer panels.

d) During these traverses, moisture is thrown to the outside where it is caught by the many moisture collection hooks.

e) Dry steam of 99.9% quality exits the top of the steam dryer unit.

f) Removed moisture drops down into collecting troughs and is routed to the outside of the dryer assembly and into the downcomer annulus area by means of drain pipes.

d. Dryer Installation (Figure 24 and Drawing 104R935)

1) Lifted by 4 eye bolts by use of a strong back and the Reactor Building overhead crane.

2) Strong back is the same one that is used to install and remove the shroud head.

3) Proper azimuth alignment is provided by 2 dryer guide rods 180° from each other that are attached to brackets welded to the reactor vessel wall.

4) Slots in the sides of the dryer mate with the guide rods.

5) Dryer is supported vertically in the reactor vessel on brackets welded to the reactor vessel wall.

6) Four hold down assemblies on the inside of the vessel head prevent the dryer from lifting during high steam flow transients.

22. Materials Surveillance Sample Program (Figure 26)

a. Purpose

To monitor the effect of fast neutron exposure (fluence) on the mechanical properties of the reactor vessel steel.

b. Description of Program and Hardware

1) Samples of the vessel carbon steel parent metal, weld metal and weld heat affected zone metal are used.

2) Sufficient samples are placed in the reactor vessel to permit measurement of changes to the vessel mechanical properties throughout the 40 year vessel life.

3) Types of test specimens used:

Charpy V-Notch Test Bars - for checking shifts in nil-ductility transition temperatures

(Nil-ductility transition temperature is that temperature below which low alloy carbon steel fractures in a brittle rather than in a ductile manner.)

Tensile Specimens	- for monitoring shifts in tensile properties (yield strength and ductility)
Flux Monitoring	- To determine the fast flux fluence received by the test specimens and vessel metal. Consists of iron, nickel and copper dosimeter wires.

4) Specimens and flux monitors are sealed in leak tight metal capsules having a dry helium atmosphere.

5) The individual encapsulated specimens and dosimeters are then placed in baskets.

Six baskets are hung on the reactor vessel wall opposite the core mid-plane where they will receive the highest fast neutron exposure (See Figure 26).

6) In addition, there are three sets of specimens and dosimeters that are hung from the top guide in order to get accelerated fast neutron exposure data.

7) The specimens are removed and sent to a hot cell laboratory and tested according to the following schedule.

Vessel Wall Specimens	Top Guide Specimens
1, 2, 4, 8, 16 and 32 years	1, 2 and 4 years

c. Installation

1) Wall Mounted Assemblies

a) Basket assemblies are suspended from brackets on the reactor vessel wall in 6 different locations.

b) Upper part of basket is spring loaded to hold the assembly in place.

c) A screw approximately 1/2 way down the basket assembly is adjusted to bear against the vessel wall to assure that there is no vibration in the basket assembly.

2) Top Guide Mounted Assemblies

Are hung from the top guide.

F. OTHER REACTOR VESSEL COMPONENTS AND RELATED COMPONENTS

1. Vessel Head and Closure (Figure 27)

a. Vessel Flange

1) Heavy flange is welded to the cylindrical portion of the reactor vessel.

2) 92 studs screw into the vessel flange

b. Vessel Head and Flange

1) Hemispherical head fabricated in the same manner as the bottom head.

2) Head flange has bored holes to permit slipping the head over the studs in the flange.

3) Inside surface of the head does not have a stainless steel weld overlay (Earlier plants did have overlay on the heads).

c. Studs, Nuts and Washers

1) Studs screw into a bushing in the vessel flange. (Bushings not used on later plants.)

2) Bushing is provided as a safety measure.

In case threads are damaged, no repair work is required on the reactor vessel parent material.

3) Castellated nuts are used to secure the head in place.

4) Spherical washers are used to assure that the force of the nuts is evenly distributed on the top surface of the head flange.

d. Flange Seal

1) Consists of 2 concentric "O" rings.

2) "O" ring material is silver plated Inconel.

3) Keepers that screw into the head flange hold the "O" rings onto the head for ease of installation.

4) Note: Ruber "O" rings are generally used for cold vessel hydrostatic tests during construction since their cost is only a fraction of the metallic "O" ring cost.

e. Stud Protectors and Guide Caps

1) Aluminum "cans" are fitted over each stud prior to installation or removal of the head to protect the stud threads.

2) Three guide caps are bolted to the tops of 3 stud protectors at 120° intervals to help guide the head into place during installation.

f. Head Installation

1) This is a complex process and only the basics will be discussed here.

2) Following setting of the head, the stud protectors are removed and the spherical washers and nuts are installed.

3) Measuring rods are installed in each stud.

4) The temperature of the entire flange area is brought to greater than 100°F and stabilized.

5) Stud tensioning devices clamp onto the threaded stud and bear upon the top surface of the head flange.

6) The studs are stretches a prescribed amount as measured by a dial micrometer on top of the stud. (Stud stretches, measuring rod doesn't.)

7) The nut is run down to take up the slack and the tensioner is then backed off.

8) This tensioning operation has to be done twice for each stud.

   Once for the initial pass to seat the "O" rings
   Once for the final tensioning

9) Typically 4 tensioners at 90° are used simultaneously to decrease the installation time.

10) Measuring rods are removed and top insert plugs are installed to keep out water and crud which could affect the accuracy of subsequent bolt elongation measurments.

11) Effects of Over and Undertensioning

<u>Undertensioning</u> - will result in inadequately seating the "O" rings and will permit leakage.

<u>Overtensioning</u> - will actually "rotate" the flange surfaces somewhat so that the outside surfaces pull together and the inner surfaces ("O" ring seal area) pull apart resulting in leakage.

2. Vessel Insulation (Figures 28 and 29)

a. Purpose

To minimize the heat loss in the primary system.

b. Description

1) Type of Insulation (Figure 28)

a) Reflective insulation of layered stainless steel.

b) Fabricated in panels that are held together with snap buckets.

2) Overall Configuration (Figure 29)

a) Top head insulation is fabricated as a single unit.

Has to be removed in order to remove the reactor vessel head.

Note: The cylindrical insulation around the top head nozzles can be removed separately to permit disconnecting the piping attached to these nozzles.

b) Insulation on the reactor vessel nozzles is removable to permit periodic in-service ultrasonic examination of the nozzle welds.

c) On plants up through Cooper, the insulation on the cylindrical part of the vessel is not removable for in service inspection as there is too little room between the biological shield and the vessel to permit removal of the insulation, inspection and re-installation of the insulation.

Plants built after Cooper have the capability for in-service inspection of all vessel welds.

3. Biological Shield (Figures 3 and 30)

   a. Purpose

      1) Reduce neutron and gamma radiation from the reactor to

         a) Permit drywell access and maintenance with minimum radiation exposure to personnel.

         b) Extend the life time of drywell components such as cable insulation to the design life of the plant (prevents gamma radiation degredation of organic compounds).

         c) Prevent neutron activation of components within the drywell and the resultant radiation exposure to personnel.

   b. Description (Figure 3)

      1) Basic Structure

         a) Cylindrical structure of high density concrete (magnetite) having vertical I beam support columns and steel outer skins (inside and out).

         b) Supported off of the reactor pedistal.

      2) Nozzle Access Openings (Figure 30)

         a) Access openings are provided around the nozzles to permit removal of the insulation for in service inspection during outages.

         b) Access Opening Components

            (1) Steel Gates - provide gamma shielding
                hinges permit opening gates for access

(2) Permali Shielding - poly impregnated plywood provides neutron shielding

Several layers, each layer ~1" thick

Total depth ~1 ft.

4. Control Rod Drive Housing Support Network (Figure 31)

   a. Purpose

      1) To prevent the rapid ejection of a control rod in the unlikely event of a control rod drive housing failure with the reactor at pressure.

      2) Some typical Engineered Safeguards are:

         Emergency Core Cooling System
         Standby Coolant Supply System
         Steam Flow Restrictions
         Control Rod Velocity Limiters
         Control Rod Drive Housing Supports
         Standby Liquid Control System

   b. Description:

      1) Support beams are founded on the inside of the concrete reactor pedestal.

      2) Hanger rods with spring washers are suspended from the beams.

      3) Grid clamps, grid plates and support bars are bolted to the hanger rods to vertical support the bottom end of each housing and drive.

      4) Installed to provide approximately a 1" gap between bottom of the drive and the support steel when the reactor is cold.

         Gap reduces to ~1/4" when the reactor is hot (CRD housings expanded downward while vessel skirt expands upward.)

      5) If a housing fails, the support system limits drive travel in the outward direction to 3".

G. REACTOR VESSEL FLOWS AND CORE FLOODABILITY

1. Flow Paths and Flow Rates (Figure 32)

a. Core Flow

Driving flow from jet pump risers	34.2×10^6 lbs./hr.
Driven flow from annular region into jet pumps	68.3×10^6 lbs./hr.
Total Core Flow	102.5×10^6 lbs./hr.

1) Flows Out:

Steam flow	13.38×10^6 lbs./hr.
Flow to Cleanup System	0.13×10^6 lbs./hr.
Total Flow Out	13.51×10^6 lbs./hr.

2) Flows in:

Feedwater Flow	13.33×10^6 lbs./hr.
Control Rod Drive System combined cooling and return water flows	0.05×10^6 lbs./hr.
Total Flow In	13.51×10^6 lbs./hr.

Note: Recirculation driving flow not included in above figures.

2. Core Floodability (Figure 33)

a. Applicability

1) Applicable to a loss of coolant accident.

2) The worst case loss of coolant accident is a 28" recirculation suction line break with the reactor at full power, steady state.

3) In this case the core will become completely uncovered.

4) This will be discussed in detail during the Emergency Core Cooling System presentations.

b. Design Features

1) The Emergency Core Cooling Systems and the reactor vessel design must be compatible so that following a loss of coolant accident, the core can be adequately cooled.

2) There are several systems that will provide water to the reactor following a loss of coolant accident.

3) One of these systems is the Low Pressure Coolant Injection System (LPCI) mode of RHR.

4) For simplification, only the LPCI system will be discussed here.

5) The LPCI system injects water into the reactor vessel using the RHR pumps via both recirculation inlet lines and down the 20 jet pumps.

6) This flooding water then increases the water level in the reactor starting at the bottom of the vessel and working its way up into the core.

7) When the water level reaches the top of the jet pump mixing sections, water will begin spilling out into the downcomer area and out of the vessel through the broken recirculation line.

8) This elevation where water begins to spill out of the jet pumps is 2/3 of the height of the active fuel.

9) Calculations show that if flooding of the reactor vessel is accomplished within a specified time frame and the level maintained at the 2/3 point, the core will be adequately cooled indefinitely and the integrity of the fuel cladding maintained.

a) Lower 2/3 of the Core

Cooled because it is flooded with water.

b) Upper 1/3 of the Core

Vigorous boiling in the lower 2/3 of the core provides a mixture of steam and water which, upon flowing upward cools the upper 1/3 of the core.

Long term, (after fuel decay heat has decreased), there will be less boiling in the lower 2/3 of the core to provide the flow of steam and water to cool the upper 1/3 of the core.

Fuel clad temperature would increase with time. However, it would still remain acceptable under these conditions.

10) Note: Under the above assumed conditions, water would have to be continually made up to the vessel to accommodate for the following cooling losses:

Boil off and,

Leakage through the jet pump diffuser to mixing section slip joints in the amount of ~150 gpm.

11) Note: The above discussion serves to illustrate the principle of 2/3 core coverage. Under all loss of coolant accident conditions there will be more than one Emergency Core Cooling System operating to reflood and cool the core.

The use of <u>any</u> of the Emergency Core Cooling Systems that provides water to the reactor vessel will not only provide the minimum required 2/3 core coverage but will provide complete core coverage.

H. RELATIONSHIPS WITH OTHER SYSTEMS (Figures 1 and 5)

1. Vessel Instrumentation

Level, pressure, temperature and flow sensed from

Center Top Head Nozzle
4 Instrument Nozzles
Standby Liquid Control/Core Differential Pressure Lines
Jet Pump Flow Lines
Thermocouple Pads and Bottom Head Drain Line

2. Control Rod Drive System

a. Control rod drives are mounted on CRD housings.

Cooling water enters vessel from drives.

b. Balance of Water

Return through nozzle on side of vessel.

c. Head Spray Nozzle on Head

Used to spray head area steam space (not walls of vessel) during shutdown to prevent pressure buildup upon cooldown and vessel flooding.

3. Main Steam System

Provides steam to drive the main turbine.

Also provides over pressure protection for the reactor vessel.

4. Auto Depressurization System

An emergency core cooling system which functions through the pressure relief valves on the main steam lines to blow down the vessel pressure under certain emergency conditions.

5. Feedwater System

Provides high purity makeup water to the reactor to replace steam sent to the turbine.

6. High Pressure Coolant Injection System (HPCI)

a. Provides water to the reactor vessel to cool the core in the unlikely event of a loss of coolant accident.

b. Motive power is steam from one of the main steam lines which drives a turbine.

c. Water enters the reactor via the feedwater lines.

7. Core Spray System

Provides for low pressure spraying of the core in the unlikely event of a loss of coolant accident.

8. Recirculation System

Provides forced circulation of the reactor coolant to yield higher reactor power output than would be possible under natural circulation conditions.

9. Reactor Water Cleanup System

a. Purpose is to maintain the reactor coolant at high purity and to permit draining water from the vessel to maintain water level during startup.

b. Suction taken from recirculation loop suction line and bottom head drain.

c. Returns through the feedwater lines.

11. Shutdown Cooling Mode of RHR

a. Provides for the removal of decay heat from the fuel during normal plant shutdown.

b. Suction taken from the "A" recirculation loop suction piping.

c. Returns through both recirculation loop discharge piping.

12. Low Pressure Coolant Injection System (LPCI) Mode of RHR

a. Provides flooding water to the reactor via the recirculation discharge piping to cool the core in the event of a loss of coolant accident.

13. Standby Liquid Control System (SBLC)

Used to inject neutron absorbing sodium pentaborate solution into the reactor to shut it down in the unlikely event of failure of the Control Rod Drive and/or Reactor Protection Systems.

14. Neutron Monitoring Systems

a. Consists of:

Source Range Monitoring System (SRM)
Intermediate Range Monitoring System (IRM)
Local Power Range Monitoring System (LPRM)

b. Provides for monitoring of reactor power under all modes of operation.

15. Reactor Protection System

A system of sensors and relays which scrams the reactor upon receipt of signals which represent potentially unsafe conditions to the reactor.

I. TECHNICAL SPECIFICATIONS

1. Pressure Limitations

a. Limitation

The reactor coolant system pressure shall not exceed 1325 psig at any time when irradiated fuel is present in the reactor.

Note: The reactor coolant system refers to everything attached to the reactor vessel and extending out to the isolation valves.

b. Where Measured

In the vessel steam space (dome)

c. Basis for Limitations

1) Based upon the more restrictive allowable pressures for

Reactor Vessel and
Piping and Related Equipment

2) Piping Limits

a) Design

Suction - 1148 psig
Discharge - 1326 psig

b) Piping code allows a 20% overpressure during transients or:

120% x 1148 = 1378 psig
120% x 1326 = 1591 psig

3) Reactor Vessel Limits

a) Designed to 1250 psig

b) Boiler code allows a 10% overpressure during transients or,

110% x 1250 = 1375 psig

4) 1375 psig vs. 1325 psig

a) It must be assumed that the entire reactor coolant system is full of water when the overpressure transient occurs.

b) Pressure is highest in the reactor coolant system at the lowest point in the system.

c) Even though this low point in the system is the Recirculation System suction piping, it is assumed for conservation that the more stringent reactor vessel limitations apply.

d) Since pressure is measured in the steam space, correction for this static head of water (~50 psig) must be applied.

This is the reason for not exceeding 1325 psig as indicated on Control Room instrumentation.

d. How Reactor Vessel is Protected from Overpressure

1) Through proper operation of the reactor

2) Through relief and safety valves on main steam lines during abnormal conditions.

3) Through the Reactor Protection System which will scram the plant upon receipt of signals which indicate potentially unsafe conditions.

2. Thermal Limitations

a. Limitations

1) The average rate of reactor coolant temperature changes during normal heatup or cooldown shall not exceed 100°F./hr. when averaged over a one hour period.

b. Where Measured

The following will be permanently recorded:

Steam Dome Pressure (Converted to Upper Vessel Temperature)
Reactor Bottom Drain Temperature
Reactor Vessel Shell Adjacent to Shell Flange
Recirculation Loops A & B
Reactor Vessel Bottom Head Temperature

c. Basis for Limitations

1) 100°F./hr. Heatup Rate

a) Provides for efficient but safe plant operation.

b) When maintained, it assures that stresses caused by thermal transients are within those analyzed.

3. Pressurization Temperature (Figures 34 and 35)

a. Purpose of Limitations

To specify the minimum temperature for a given reactor pressure for the following modes of operation:

In-Service Pressure Testing
Subcritical Heatup and Cooldown
Operations with the Core Critical

b. Limitations

1) During all operations with a critical core, other than for low level physics tests, except when the vessel is vented, the reactor vessel shell and fluid temperatures shall be at or above the temperature of curve #3 of figure 34 (Figure 3.6-1 in Tech. Specs.).

2) During heatup by non-nuclear means, except when the vessel is vented, cooldown following nuclear shutdown on low-level physics tests, the reactor vessel temperatures shall be at or above the temperatures of curve #2 of figure 34.

3) The reactor vessel shell temperatures during inservice hydrostatic or leak testing shall be at or above the temperatures shown on curve #1 of figure 34.

This curve to be modified by the increase in temperature required by neutron exposure as shown in Figure 35 (Figure 3.6-2 in Tech. Specs.).

4) The reactor vessel head bolting studs shall not be under tension unless the temperature of the vessel head flange and the head is greater than 100°F.

c. Basis for Limiations

1) Brittle fracture in reactor vessel materials.

a) All ferritic steels including plain carbon steels and low alloy steels can break in a brittle manner at low temperatures, typically below -10°F.

b) The low alloy steel used in the construction of the reactor vessel falls into this category.

c) Under unusual circumstances, the temperature at which brittle fracture occurs for the reactor vessel steel can be within the temperature range over which the reactor can be expected to operate.

d) Austenitic stainless steel alloys used in reactor components, such as the shroud, shroud head, etc., can break in a brittle manner at temperatures in the -200°F. to -300°F. range.

This temperature range is well below any that the vessel will see.

Revision ______________

Date ______________

BWR SYSTEMS

LESSON PLAN

A. REACTOR VESSEL PROCESS INSTRUMENTATION

B. REFERENCES

1. BWR Systems Manual Chapters 2.2 and 3.2
2. GEK 32555 - Nuclear Boiler System (Brown's Ferry)
3. GEK 32556 - Reactor Protection System (Brown's Ferry)
4. GEK 32550 - Feedwater Control System (Brown's Ferry)
5. GEK 779 - Volume V - Instruction Manuals for Vendor Supplied Equipment
6. Final Safety Analysis Report - Brown's Ferry Nuclear Plant
7. Card File Index - Chapter 2.2

C. OBJECTIVES

1. Fully understand the purpose of the system and its design objectives.
2. Know the types and ranges of instruments comprising the Reactor Vessel Instrument System.
3. Learn all setpoints and trip functions associated with the various instruments.
4. Know the underlying reasons behind these setpoints and trip functions.
5. Learn the Technical Specifications pertaining to the system.
6. Become familiar with control room readouts.

D. GENERAL DESCRIPTION

1. Design Basis

   a. Provide the operator with sufficient information in the control room to protect the vessel from undue stresses.

b. Provide information which can be used to assure that the reactor core remains covered with water and that the separators are not flooded.

c. Provide automatic, redundant, reliable inputs to the Reactor Protection System (RPS) to shut the reactor down when fuel damage limits are approached.

d. Provide automatic initiation of the Emergency Core Cooling System (ECCS) and the Primary Containment Isolation System when safe operational parameters are grossly exceeded.

e. Provide a method of detecting leakage from the reactor vessel head flange seal.

2. Processes measured include:

   a. Vessel Level

   b. Vessel Pressure

   c. Vessel Temperature

   d. Jet Pump and Core Flow

   e. Vessel Flange Seal Leakage

E. COMPONENT DESCRIPTION

1. Vessel Level Instrumentation

   a. Definitions (Figure 1)

      1) Reactor Vessel Zero

         a) Reactor pressure vessel bottom head invert (the top of the bottom head)

         b) Provides reference for all incore components and vessel nozzle taps

      2) Instrument Zero

         a) 528" above vessel zero

   b. Four Ranges of Level Indication (Figure 2)

1) Normal Control Range

   a) 0 - 60" span covering normal operating range.

   b) Referenced to instrument zero.

   c) GEMAC Instruments (3) used by Feedwater Control System

      (1) Temperature Compensated by a Pressure Signal

      (2) Most accurate level indication available to the operator

   d) Yarway Instruments used for Trip Functions (later)

      (1) Not Temperature Compensated

      (2) Calibrated for Normal Operating Reactor Pressure

      (3) Used for trip functions because a Yarway Instrument does not require electrical power for indication.

   e) 3 control room indicators and one recorder monitor this range of level indication - all Feedwater Control System Instruments

2) Emergency System Range

   a) -155" to 60" span covering normal operating range and down to the lower instrument nozzle.

   b) Referenced to instrument zero

   c) Temperature compensated via heat clamps between reference and variable leg.

   d) Provides trip functions associated with the level instrumentation.

   e) Calibrated for normal operating reactor pressure

   f) Two control room indicators monitor this range of level indication

3) Shutdown Vessel Flooding Range

   a) 0" to +400" span covering upper portion of reactor vessel

b) Referenced to instrument zero.

c) No temperature compensation

(1) Calibrated for cold (<212^{o}F., 0 psig) moderator temperature. A calibration curve must be used at other than zero psig to find actual level.

d) Provides level indication during vessel flooding on cooldown.

(1) No trips or alarms associated with this range.

e) One control room indicator monitors this range of level indication

4) Post Accident Flooding Range

a) -100" to +200" span covering active core area and overlapping the lower portion of the Emergency Systems Range

b) Instrument zero for this instrument is 360" above vessel zero, which is the top of the active fuel.

c) No Temperature Compensation

(1) Intended for use only under accident conditions with reactor at 0 psig and recirc pumps tripped.

(2) Variable leg tap is from diffuser of jet pumps 1 and 6 (or 11 and 16). Flow through the jet pump interferes with the variable leg signal rendering instrument indication inaccurate.

d) Provides indication during and after a loss of coolant accident. It also provides a signal to interlock the Containment Cooling Mode of the Residual Heat Removal System (RHR).

(1) Prevents using the RHR System for containment depressurization when it is needed to flood the core region.

e) The 0" to +100" portion of this range is recorded in the control room and two indicators monitor the full range of these instruments.

c. Level Instrumentation and Piping Layout (Figure 3)*

1) Condensate Chambers

a) Piping run is uphill from vessel to chamber.

(1) Allows excess chamber condensation to overflow back to reactor vessel.

b) Normal Control and Post-Accident Flooding Ranges share a common condensing chamber.

c) Piping runs are insulated and as short as practical.

d) Condensate chambers are unlagged.

2) Yarway Column (Figure 4)

a) Provides physical temperature compensation. Compensation required since external reference leg is colder (denser) than internal variable leg (at operating pressure).

(1) Steam condensing in the condensate chamber keeps the reference leg full.

(2) Piping is run downhill into condensate chamber to ensure adequate condensate in the chamber.

(3) Excess condensation overflows into the variable leg.

(4) A natural circulation effect keeps variable leg condensate recirculating back into the vessel.

(5) As a result, the variable leg is kept hot (~500°F.).

(6) Heat transfer clamps maintain reference leg temperature at ~290oF.

b) Auxiliary Chamber Operation

(1) Normally full of cool (<150°F.) water.

(2) In the event of a rapid decrease in reactor pressure, condensate chamber may begin to flash, decreasing reference leg height.

*Figure 3 shows only half of the level instruments (with the exception of the shutdown, vessel flooding range of which there is only one instrument).

(3) As the condensate level drops uncovering the auxiliary chamber part, cool water flows into the condensate chamber:

(a) Quenching the Flashing Action

(b) Restoring the Reference Leg Level

(4) The equalizing tube allows steam to flow back into the auxiliary chamber where it condenses.

(5) Without this action, the reference leg height would decrease, giving the appearance of an increase in actual vessel level.

Note: The other condensate chambers do not need the auxiliary chamber since they operate at a much lower temperature (<150^{o}F.).

d. Level Instrument Functions

Type	Indicated Range	Setpoint(s) (Indicated)	Function
Normal Control Range	0" to 60"	NA	Provides level inputs to the Feedwater Level Control System
		+54"	1) Trips Main Turbine* 2) Trips Reactor Feed Pumps* 3) Trips High Pressure Coolant Injection Turbine 4) Trips Reactor Core Isolation Cooling System Turbine

*Function of Feedwater Level Control System

Type	Indicated Range	Setpoint(s) (Indicated)	Function
		+39"	High Level Alarm*
		+33"	Normal Operating Level
		+27"	1) Low Level Alarm*
			2) In-conjunction with RFP Trip, initiates Recirculation Pump Runback.*
		+10"	1) Reactor Scram
			2) Containment Isolations
		+18	1) Permissive to Automatic Depressurizations System
			4) Start Standby Gas Treatment System
Emergency Systems Range	-155" to -60"	-51.5"	1) Initiates the High Pressure Coolant Injection System (HPCI)
			2) Initiates the Reactor Core Isolation Cooling System (RCIC)
			3) Main Steam Line Isolation
			4) Recirculation Pump Trip

*Function of Feedwater Level Control System

Type	Indicated Range	Setpoint(s) (Indicated)	Function
Emergency Systems Range		-143.5"	1) Initiate Core Spray 2) Initiate Residual Heat Removal - Low Pressure Coolant Injection Mode 3) Permissive to Automatic Depressurization System 4) Start Diesel Generators
Shutdown, Vessel Flooding Range	0" to +400"	None	Level indication during vessel flooding
Post Accident Flooding Range	-100" to +200"	-39"	Pevents inadvertent operation of containment cooling during accident conditions.

1) Note that the level setpoints at +10", -51.5" and -143.5" are commonly referred to as low, low-low and low-low-low water level respectively.

e. Level trip settings were chosen for the following reasons:

Note: All levels shown are indicated levels.

1) Main Turbine, Reactor Feed Pump Turbine, High Pressure Coolant Injection Turbine and Reactor Core Isolation Cooling Turbine Trip at +54".

a) +54" level is point above which moisture carryover becomes much more pronounced. Turbine blading may be damaged if operation continued above this level.

b) In addition, tripping all but the main turbine prevents feedwater from overflowing into main steam lines during pressurized operation. Water "slugs" in steam line may cause hydraulic pressure surges which may lift safety/relief and/or safety valves.

2) High Level Alarm at +39"

a) Defines upper end of normal operating region.

b) If level is $\leq$+39", transients such as a recirculation pump trip will not cause level to increase to turbine trip point (+54").

3) Low Level Alarm at +27"

a) Defines lower end of normal operating region.

b) If level is $\geq$+27", transients such as a reactor feed pump trip from full power will not cause level to decrease to reactor scram point (+10") with a runback of the recirculation pumps.

4) Reactor Scram at +10"

a) Assures the reactor will not be operated without sufficient water above the reactor core.

b) In conjunction with the containment isolation signal of +10", prevents fuel cladding perforation.

c) Prevents operation with separator skirts uncovered. Carryunder could result with:

(1) Reduces core inlet subcooling

(2) Reduces jet pump and recirculation pump net positive suction head.

d) Set low enough to prevent spurious operation for normal operating transients

5) Containment Isolations at +10"

a) In conjunction with the reactor scram setting (+10"), initiates closure of certain primary system isolation valves to limit inventory loss and prevent fuel cladding perforations and release of excessive quantities of radioactive products to the environment. Starting SBGTS establishes secondary containment.

6) HPCI and RCIC System initiation at ~~-31.5"~~ -5.5"

   a) HPCI initiates at -31.5" -5.5" is set to allow adequate core cooling for small line breaks.

   b) RCIC initiation at -31.5" -5.5" is set to provide adequate cooling under loss of feedwater flow and/or main steam isolation conditions.

7) Main Steamline Isolation at ~~-31.5"~~ -5.5"

   a) Initiates closure of Group I isolation valves to prevent excessive release of radioactive products to the environment and loss of vessel inventory.

8) Recirculation Pump Trip at ~~-31.5"~~ -5.5"

   a) Prevents operation of recirculation pumps without adequate net positive suction head.

9) Diesel Generator Start Signal at -143.5"

   a) Starts Diesels so that they are already up to proper speed and voltage in the event of a subsequent loss of normal power.

      (1) If normal power was already lost, Diesels will start and automatically close onto the emergency buses when they reach proper speed and voltage.

10) Emergency Core Cooling System (ECCS) Initiation Signal at -143.5"

   a) Set low enough to prevent spurious operation

   b) Set high enough to allow time to activate the low pressure ECCS so that no fuel melting will occur. Long term cooling will be possible with no fuel meltdown.

11) 2/3 Core Covered Permissive Interlock at -39"

   a) Allows Residual Heat Removal (RHR) System to be used for containment spray.

   b) If core has been reflood to at least 2/3 core height, sufficient water is available to keep core cool. The upper 1/3 of the core will be cooled by flashing steam.

f. Steam Flow Effect on Reactor Water Level (Figure 5)

1) Steam flowing through the dryers is forced to change direction several times, resulting in a pressure drop across the dryers.

2) At 100% steam flow, the pressure drop is ~7" of water.

3) Therefore, at 100% steam flow, P_1 is 7" of water less than P_2.

4) The level outside the dryer skirt (downcomer region) is 7" higher than inside the skirt.

5) Since the vessel level instruments compare the reference column height to the downcomer (variable column) height, setpoints are adjusted to compensate for this error.

6) The water level inside the dryer skirt is slightly dome shaped.

a) Moisture separator drains must flow to the outside (downcomer) region to return to the core.

b) In order for drains from the interior separators to flow outward, a hydraulic gradient is required.

c) At 100% power, the "top" of the dome is ~4" higher than the "outside", providing the hydraulic gradient.

Note: The degree of hydraulic gradient is variable, ranging from 0" at 0% power to 4" at 100% power.

g. A single overall reactor differential pressure instrument also utilizes the level piping.

1) Range 0 - 50=

2) Used to evaluate jet pump performance during initial startup testing.

3) No operational significance.

2. Reactor Pressure Instrumentation and Piping Arrangement (Figure 6)

a. Utilizes same piping as vessel level instrumentation

b. Control Room Indications (Panel 9-5)

Instrument	Type	Indication
Narrow Range Reactor Pressure	Recorder	950 - 105- psig
Reactor Pressure	3 Indicators	0 - 1200 psig
Wide Range Reactor Pressure*	Recorder	0 - 1500 psig

c. Pressure Instrument Functions

Type	Setpoint(s)	Function
Pressure Switches (4)	230 psig	Signal Recirculation Discharge Valves to Close for Residual Heat Removal Logic
Pressure Switches (2)	450 psig	1) Permissive for opening core spray and Residual Heat Removal admission valves. 2) In conjunction with high drywell pressure (+2 psig) initiates core spray and Low Pressure Coolant Injection
Pressure Switches (2)	600 psig	Interlocks the Mechanical Vacuum Pumps if Reactor Pressure >600 psig and condenser vacuum >22" Hg.
Pressure Recorder	1040 psig	Reactor High Pressure Alarm
Pressure Switches (4)	1055 psig	Reactor Scram Signal

*Functions from FWCS Pressure Recorder

Type	Setpoint(s)	Function
Pressure Switches (4)	1055 psig	Automatically bypasses main condenser low vacuum or main steam isolation valve closure (only if the Mode selector switch is not in Run).
Pressure Switches (4)	1120 psig	Initiates Recirculation Pump Trip for Anticipated Transient Without Scram
Pressure Indicating Transmitters	0 - 1500 psig	Provide temperature compensation for vessel level signal (Feedwater Control System)

d. Pressure switch settings were chosen for the following reasons:

1) 230 psig

a) Recirculation Discharge Valves close on Loss of Coolant Accident for RHR Logic, ensures RHR Injection into Reactor Vessel

2) 450 psig

a) Permissive for RHR and Core Spray ECCS Logic and operation. Low pressure systems will not inject above this pressure even if valves were open and pumps were running.

3) 600 psig

a) Does not allow operation of Mechanical Vacuum Pump when not needed to maintain condenser vacuum at pressures where significant radioactivity could be released.

4) 1040 psig

a) Alert operator of impending high pressure condition.

5) 1055 psig

a) Reactor scram at this pressure prevents possible violation of the Nuclear Steam Supply System pressure safety limit.

b) Reactor scram, in conjunction with relief and/or safety valve operation, limits pressure transient experienced during a turbine trip at high power conditions.

6) 1055 psig

a) Startup testing on KRB revealed possible core instabilities during operation at >600 psig and main steam isolation valves closed.

b) Recent tests indicate this interlock may be unnecessary, setpoint has been raised to allow Hot Standby Operation (subcritical, MSIV's closed) at normal operating pressure.

7) 1120 psig

a) Trips recirculation pumps, in the event the RPS scram function fails, tripping these pumps will reduce core power to within the safety and safety relief valve capacity.

3. Vessel Temperature Instruments

a. Provides indication of vessel shell, flange and support skirt temperatures.

b. Allows operator determination of temperature gradients and the resulting stresses.

c. Such monitoring is especially important during heatup, cooldown and transient conditions.

d. 46 copper-constantan thermocouples with braided glass insulation and stainless steel cladding are positioned on vessel.

1) Thermocouple Pad Locations (Figure 7)

a) Vessel Support Skirt

b) Vessel Head Stud Bolt

c) Vessel Flange

d) Feedwater Nozzle (3)

e) Vessel Shell (Above and Below Normal Water Level)

f) Above Vessel-to-Skirt Junction

g) Vessel-to-Skirt Joint

h) Bottom Head

i) Vessel Drain Line to Cleanup System

j) Vessel Flange-to-Shell ΔT

2) 32 additional thermocouples are installed on the vessel and hooked up to the junction box but do not readout in the control room.

3) Thermocouple Installation

a) Most consist of two adjacent pads welded onto the vessel during fabrication (Figure 8).

(1) One pad has a thermocouple sheath clamping screw.

(2) The other holds the hot junction of the thermocouple against the vessel surface.

b) Thermocouples measuring the vessel head and head flange areas are magnetically clamped.

(1) Easily removed during vessel head removal.

(2) Can be positioned for optimum temperature measurement.

c) Another thermocouple is inserted into a drilled out vessel head bolt.

e. The vessel shell-to-flange ΔT is measured to limit thermal stress on the shell-to-flange weld.

1) The flange is very massive and changes temperature slower than the shell.

f. Vessel shell heatup and cooldown rate limitations are both 100°F./hr.

4. Jet Pump and Core Flow Instruments

a. Plant power output is proportional to the ability to remove the heat generated (core flow). Accurate flow measurements are required to evaluate reactor power level.

b. Since the total flow of coolant must pass through the jet pumps to reach the core inlet plenum, flow is measured in each jet pump and summed to yield total flow.

c. Each jet pump has a pressure tap on the pump throat. This pressure is compared to the core inlet plenum pressure to produce a differential pressure signal proportional to flow.

1) Core inlet plenum pressure is essentially jet pump discharge pressure.

2) Individual jet pump differential pressures are indicated in the control room.

d. The square root of the differential pressure is a signal representing flow.

e. Core Flow Measurement (Figure 9)

1) Flow for jet pumps 1 through 5, 6 through 10, 11 through 15 and 16 through 20 are summed.

2) Summed flows for 1 through 5 and 6 through 10 are again summed to give "A" recirculation system jet pump flows; and similarly 11 through 15 and 16 through 20 to give "B" loop flows.

3) These loop flows are summed to give total core flow.

4) In the event one recirculation pump is secured, that loops jet pumps will have reverse flow, and the inactive loop's flow to give a more accurate core flow indication.

5) Total core flow is recorded in the control room.

f. Fully Instrumented Jet Pumps

1) Four jet pumps were calibrated at a test facility and then installed, one per quadrant.

2) The other 16 jet pumps were then calibrated against them.

3) The fully instrumented jet pumps have additional pressure taps.

a) One on the pump throat

b) One on the pump diffuser

c) Flow indication is displayed in control room.

4) Jet pumps 1, 6, 11 and 16 are fully instrumented.

5) The lower taps on the instrumented jet pumps also provide the variable leg signal to the post accident flooding level indication.

g. Abnormal differences in flow indications between jet pumps may be indicative of an inoperative jet pump. Refer to the Recirculation System Lesson Plan for more information.

h. Core Plate Differential Pressure

1) Compares standby liquid control injection line pressure (below core plate) to above core plate pressure.

2) May be used to determine long term trends in the indicated core flow and core plate differential pressure relationship.

5. Vessel Head Flange Leak Detection (Figure 10)

a. Detects leakage from the inside of the reactor vessel past the inner seal ring.

b. The detection line is connected to a drilled passage in the vessel flange.

c. Any inner seal leakage is piped to a collection chamber installed between 2 air operated valves.

d. A level switch detects accumulation of water in the chamber.

e. A pressure switch detects abnormally high pressure in the collection piping.

f. Solenoid operated control valves are de-energized in the monitor position.

g. Placing the switch in the drain position energizes both control valves, reversing the position of the isolation valves.

1) This blocks the leakage and drains the detection circuit to the Drywell Equipment Drain Sump.

h. Return the switch to Normal.

i. The leakage rate may be determined by timing the period required to activate the level alarm again.

Note: GE strongly recommends that operation of the collection chamber isolation valves be avoided once leakage through the first seal is detected. Operating experience has shown that the amount of steam leakage past the first seal increases after each operation of the collection chamber fill and drain valves which will wire draw flange sealing surface.

j. Failure of both flange seals is detected by the primary containment leak detection system.

k. Note that it is possible to fill the sensing line with water during refueling operations. If the line is not drained prior to heatup, an erroneous inner seal leak will be annunciated.

F. OPERATIONAL SUMMARY

1. Protective System Philosophy

a. Redundant sensors employed to reduce probability of system failure.

b. Trips or protective actions are initiated from level or pressure switches only.

c. Switches serve but one function and that is to transmit trip functions.

d. All signals required for remote (control room) level and pressure indication/recorders are completely independent of the protective circuitry.

e. Failure of remote recorders or indicators will not prevent proper protective system response.

G. SYSTEM INTERRELATIONSHIPS

1. Level

a. Normal Control Range Inputs to:

1) Feedwater Control System

2) Main Turbine Trip Control Circuit

3) Reactor Feedwater Pump Control Circuit

4) High Pressure Coolant Injection Turbine Trip Control Circuit

5) Reactor Core Isolation Cooling Turbine Trip Control Circuit

6) Reactor Protection System

7) Containment Isolation System

8) Recirculation Flow Control System

b. Emergency Systems Range Inputs to:

1) Emergency Core Cooling System Controls

2) Reactor Core Isolation Cooling System Controls

3) Containment Isolation System

4) Recirculation MG Set Control Circuit

5) Diesel Generator Control Circuit

c. Post Accident Flooding Range Inputs to:

1) Residual Heat Removal System Control Circuit

2. Pressure

a. Reactor Pressure Inputs to:

1) Emergency Core Cooling System Control Circuitry

2) Reactor Protection System

3) Mechanical Vacuum Pump Control Circuit

4) Recirculation MG Set Control Circuits

5) Feedwater Control System

H. TECHNICAL SPECIFICATIONS

1. Technical Specifications associated with vessel instruments are too numerous to enumerate here. Refer to the references for the various sections in Tech. Specs. and in Lesson Plans for systems using this instrumentation.

Revision ______________

Date ______________

BWR SYSTEMS
LESSON PLAN

A. FUEL

B. REFERENCES

1. BWR Systems Manual, Chapter 2.3

2. Desification Considerations in BWR Fuel; NEDM-10735, Supplement 5

3. GE Nuclear Engineer's Manual, GEI-92823B

4. Pre-Conditioning Interim Operating Management Recommendation (PCIOMR)

5. BWR/4 and BWR/5 Fuel Design, NEDE-20944-1P, September, 1974

6. Licensing Topical Report, GE BWR Generic Reload Application for 8 x 8 Fuel, NEDE-20360-P, April, 1974, Revisions 1, 2, 3 & 4

7. GE BWR Reload Licensing Amendment for Browns Ferry Nuclear Plant Unit 1, NEDO-24020, May, 1977

8. Final Safety Analysis Report Browns Ferry Nuclear Plant 3.2, 3.6, 3.7

9. Reference Card File 2.3

C. OBJECTIVES

1. To understand the mechanical construction and nuclear design of the fuel.

2. To understand the use of burnable poisons in the fuel and their effects on core reactivity.

3. To understand the basis and the method of "Fuel Pre-Conditioning".

4. To understand the past and present fuel problems and the corrective actions taken.

D. GENERAL DESCRIPTION

1. Power Generation Objective

a. Fuel Mechanical Design

1) To provide a high integrity assembly of fissionable material which can be arranged in a critical array. The assembly must be capable of efficiently transferring the generated fission heat to the circulating coolant water while maintaining structural integrity and containing the fission products.

b. Nuclear Design

1) To attain rated power generation from the nuclear fuel for a given period of time.

2) To attain reactor nuclear stability throughout core life.

3) To allow normal power operation of the nuclear fuel without sustaining fuel damange.

2. Safety Design Basis

a. Fuel Mechanical Design

1) The nuclear fuel shall be utilized as the initial barrier to the release of fission products. The fission product retention capability of the nuclear fuel shall be substantial during normal modes of reactor operation so that significant amounts of radioactivity are not released from the reactor fuel barrier.

b. Nuclear Design

1) Fuel nuclear design shall provide negative reactivity feedback that is sufficient, in combination with other plant systems, to prevent fuel damage as a result of any abnormal operational transient.

2) Fuel nuclear design shall exhibit such nuclear characteristics as required to assure that the nuclear system has no inherent tendency toward divergent or limit cycle operation.

3) Fuel nuclear design shall limit the excess reactivity of the core sufficiently to assure that reactivity control systems are capable of making the core subcritical at any time with the control rod of highest worth fully withdrawn.

3. Fuel Assembly Mechanical Construction

a. Fuel Bundle

1) 764 Bundles

2) Length - Approximately 15 feet

3) Length of Active Fuel - 144 inches

4) Total Weight ~620 lbs.

b. Lower Tie Plate (Fabricated from Type 304 Stainless Steel Casting)

1) Directs coolant to fuel rods.

2) Provides grid for fuel rod positioning.

3) Contains 8 threaded holes for tie rods.

4) Positions the channel relative to the fuel rods and relative to the other channels in the four bundle cell.

5) Has a nose piece which supports the fuel assembly and guides it into the fuel support piece during fuel loading.

6) All 1 inch bypass flow holes in the core support plate are plugged and two 9/32 inch holes are drilled in the lower tie plate of each reload 8 x 8 assembly.

c. Upper Tie Plate (Fabricated from Type 304 Stainless Steel Casting)

1) Positions the upper end of the fuel rods.

2) Positions the fuel channel - the outside mating configuration of machined bosses maintains the channel-to-upper-tie plate alignment.

3) Provides fuel handling capability - lifting bail.

4) Provides fuel bundle orientation.

a) Serial number stamped on handle - can be read from center of cell.

b) Bundle installed with the lug on the bail pointing toward the center of the four bundle cell.

5) Eight fuel tie-rods pass through the upper tie plate.

a) On top of the upper tie plate, the tie rods are secured with stainless steel nuts.

b) A locking tab washer is installed over each pair of adjacent tie rods (Figure 2).

(1) The tabs are bent up against the nuts to prevent rotation and loosening of the nuts.

(2) Another tab fits into a notch in the tie rod to prevent rotation and loosening of the tie rod.

d. Fuel Channel

1) Constructed from Zircaloy-4

a) Alloy of 98% Zirconium, 1-1/2% tin, and small amounts of iron and chromium.

b) Lower rate of hydride formation than Zr-2 because nickel not used in alloy.

c) Better neutron economy, lower neutron absorption cross-section than stainless steel.

d) Channels are to be used repeatedly in successive cycles.

2) Fastened to the fuel bundle with a spring clip channel fastener and one cap screw (Figure 3).

3) Purpose

a) Channels the coolant flow upward through the fuel bundle (approximately 90% of the flow is through the bundle - 10% is bypassed around the fuel bundle).

b) Provides a bearing surface for the control rod blades.

c) Provides protection for fuel rods during fuel handling.

d) Provides the primary resistance to lateral acceleration loadings on the fuel assembly (seismic loadings).

e) Correct control rod passage clearance ensured by stainless steel buttons at the top of the channel - the button mates with the button on the opposing channel.

e. Fuel Rod Spacers (Figures 4 and 5)

1) Fabricated from Zircaloy-4 sheet metal for neutron economy.

2) Located at ~20" intervals along the fuel rod (total of seven spacers).

3) Provide positive contact support for fuel rods.

4) Radially positions the rods relative to one another and relative to the fuel channel.

5) A solid support is formed for each rod by springs which push the rods against their support.

   a) Prevent fuel rod vibration

   b) Prevent fretting wear associated with fuel rod vibration

   c) On 7 x 7 and 8 x 8 bundles, Inconel-X is used for springs for reliable spring properties and characteristics. (Inconel-X is an alloy of chromium, nickel and iron.)

6) Functional requirements placed on the fuel spacer are that it must transmit the acceleration loadings imposed by the fuel rods to the channel without loss of its capability to properly position the fuel rods.

7) Spacer-Capture Rod - The spacers are held in their axial position by a spacer-capture rod.

   a) Fuel Spacer-Capture Rod (7 x 7 Bundles)

      (1) Center rod of fuel assembly - contains fuel

      (2) Segmented with square end plugs to mate with the spacer and prevent the spacer from sliding axially.

      (3) Segmented sections of the center rod are drilled to allow transport of the fission gases to the upper plenum.

      (4) Center opening of the spacer has a square shape to accommodate the fuel spacer capture rod.

      (5) Fuel spacer-capture rod has a square lower end plug shank to mate with a square hole in the lower tie plate - rod cannot rotate and release the spacers.

   b) Spacer-Capture Water Rod (8 x 8 Bundles) (Figure 4)

      (1) Located off-center of fuel assembly - contains no fuel

      (2) Hollow Zircalloy - 2 rod

(3) Several holes are drilled around the circumference of the rod at each end to allow coolant water to flow through the rod.

(4) Welded tabs relative to the axial spacer locations. During assembly, the water rod is passed through the spacer and then rotated to lock the spacer in its axial position.

(a) 14 tab water rod, design improvement to provide additional design margin.

i. Spacer grid (14 tab water rod) is positioned by a tab above and below a structural member (divider) of the spacer grid.

ii. 14 tab water rod has the following advantages over the 7 tab water rod:

- Provides a stronger positioning device
- Reduces loads induced in the water rod
- Minimizes spacer cocking
- Provides improved tolerance control

iii. Strength of spacer grid positioning device for the 14 tab water rod is improved by approximately 33% over the 7-tab design.

(b) Old design 7 tab water rod positioned spacer by being located between two structural members (bars) of the spacer grid.

(5) Bottom end plug of the water rod has a square shank which:

(a) Mates with a square hole in the lower tie plate and prevents rotation and release of the spacers.

(b) Prevents bundle assembly with the water rod in the wrong position.

(6) Effect of the Water Rod

(a) Increases moderation in the interior of the bundle.

(b) Improves neutron economy.

(c) Flattens bundle power distribution - reduces the rod-to-rod power peaking.

(d) Reduces the void coefficient of reactivity.

(e) Flattens axial power shapes by reducing the void coefficient and increasing the ratio of non-boiling-to-boiling water in the top of the core.

f. Finger Springs (Reload 8 x 8 Bundles Only) (Figure 6)

1) Sheet metal stampings

2) Positioned by the ends of the fuel rods

3) Fill the space between the channel and the lower tie plate.

4) Maintain a constant pressure against the lower tie plate and maintain a constant bypass flow.

5) Reload 8 x 8 fuel incorporates finger springs for controlling moderator/coolout bypass flow at the interface of the channel and fuel bundle lower tie plate.

g. Expansion Spring

1) Located over the top end plug pin of each fuel rod.

2) Keeps the fuel rods seated in the lower tie plate.

3) Takes up differential expansion during operation and compensates for minor differences in fuel rod lengths by sliding within the holes of the upper tie plate.

4) Protects the fuel rods against any impacts which might occur against the upper tie plate.

5) Spring fabricated from Inconel-X on 7 x 7 and reload 8 x 8 fuel.

E. COMPONENT DESCRIPTION

1. Fuel Rod (Figure 7)

a. Types of Fuel Rods

1) Standard Fuel Rods

2) Tie Rods

a) Active fuel length same as standard rod

b) End plugs threaded

3) Fuel Spacer-Capture Rod

a) Active fuel length same as standard rod

b. Cladding

1) Fuel pellets contained in Zircaloy-2 tubing. (Zircaloy-2 is ~92% Zirconium alloyed with small amounts of tin, iron, chromium and nickel.)

2) Zircaloy-2 has less resistance to hydriding than Zircaloy-4 but a better heat transfer coefficient, better neutron economy than stainless steel.

3) Cladding thickness is adequate to be "free standing" (i.e., capable of withstanding external reactor pressure without collapsing onto the pellets within).

4) Cladding surface pre-oxidized by an autoclave process making it more resistant to contamination and easier to keep clean.

c. Plenum Volume

1) Free volume for the accumulation of fission gases.

2) Sufficient volume provided to prevent excessive internal pressure from fission gases liberated over the design life of the fuel.

3) Fission products formed during operation are mostly contained within the fuel pellets - a relatively small amount is released and must be accommodated inside the rod.

d. Plenum Spring

1) Prevents movement of the fuel column inside the fuel rod during fuel shipping and handling.

2) Allows for axial expansion of the fuel pellets.

3) Keeps the fuel pellets down in the active fuel length of the fuel rod.

4) Spring is fabricated from stainless steel.

e. Hydrogen Getter (Reload 8 x 8 Only)

1) Hydrogen will combine to form a hydride of low strength which tends to migrate to local areas in the cladding. Blisters are formed which can result in fuel failure.

2) The getter is added as a precaution during fuel manufacture to avoid hydrogenous contamination (internal hydriding) in addition to hot vacuum outgassing of the fuel rod.

3) The Zirconium-based getter is 100 times more reactive with water than is the Zircalloy-2 cladding and absorbs any moisture left in the fuel rod.

4) Getter Construction

a) Zirconium alloy in the form of small chips is loosely packed in a stainless steel tube.

b) One end of tube capped.

c) Other end of tube is covered by wire screening.

f. End Plugs

1) Upper and lower end plugs are fabricated from Zircaloy-2 (Zr-2).

2) End plugs are seal welded to the fuel tube to provide a sealed tube after hot vacuum outgassing and backfilling of the fuel rod with helium gas to one atmosphere pressure. (Helium is an inert gas with a good heat transfer coefficient.)

3) Shanks on the end plugs engage the upper and lower tie plates and maintain rod position in the bundle.

4) Shanks of upper end plugs are sized according to the enrichment of the fuel rod (7 x 7 and Reload 8 x 8).

a) The larger the diameter of the upper end plug the higher the enrichment of the fuel rod.

b) The holes in the upper tie plate are drilled to mate the end plug.

c) This prevents incorrect enrichment location in the bundle.

d) It is not mechanically possible to completely put together a fuel assembly with any high enrichment rods in positions specified to receive a lower enrichment.

e) Provides visual check of fuel assembly orientation.

6) Type II and Type III fuel assemblies have a thermal barrier interposed between the bottom fuel pellets and the lower end plug of the basic fuel rods and between the connectors and their adjacent fuel pellets in the spacer capture rods.

a) The purpose of the thermal barrier is to reduce the operating temperature difference between the lower end plug (or connector) and the cladding in the weld regions.

b) The barrier consists of four close winds of 35 mil-diameter stainless steel wire with 30 mil thick stainless steel waters spot welded to each end.

c) Recent calculations and tests indicate that all stress limits are satisfied at the welds without the thermal barriers - thermal barriers will not be used in Unit 3 fuel.

g. Fuel Pellets

1) Sintered Cylinder of UO_2 or UO_2 - Gd_2O_3

a) High density ceramic uranium dioxide or uranium dioxide - Gadolinium oxide.

b) Powder cold pressed at high pressure to form pellets and then sintered in a reducing atmosphere at 1650 to 1750°C.

c) Average pellet immersion density is about 95% of theoretical density - porosity of 5% allows for collection of fission gases in addition to that accumulated in the plenum.

2) Pellet Shape

a) Shorter Fuel Pellets with Chamfered Corners (Reload 8 x 8)

(1) Length-to-diameter ratio is approximately 1.0

(2) Corners of pellets chamfered

(3) Less mechanical interaction between the fuel and the cladding.

(4) Reduced possibility of pellet-clad interaction fuel failure.

(5) Pellets are .416 inches in diameter, .420 inches in length.

b) 7 x 7 fuel pellet edges are chamfered to reduce mechanical interaction between the fuel and cladding.

3) Radial gap between fuel pellet and cladding provided to allow for pellet growth from thermal expansion and irradiation swelling.

a) Gap .012 inches, Type I, II, III

b) Gap .009 inches, Reload 8 x 8

4) Multiple Enrichments

a) Power density proportional to:

Power Density = $\phi_T \Sigma_f = \phi_T N \sigma_f$

where σ_f = fission cross-section of the fuel

ϕ_T = thermal neutron flux

N = number density of fuel atoms

b) Desirable to maintain a uniform power density across the core.

c) Greater thermal flux exists in the water gaps due to better moderation (Figure 10).

Revision ____________________

Date ____________________

BWR SYSTEMS

LESSON PLAN

A. CONTROL ROD DRIVE HYDRAULICS

B. REFERENCES

1. Boiling Water Reactor Systems Manual, Chapter 2, 4
2. Browns Ferry FSAR Chapter 3, 4
3. Browns Ferry Instrumentation and Control Manual Volume IX Part I
4. Browns Ferry Operating Instruction #85
5. Air Operated Control Valve Instruction Manual
6. Control Rod Drive Pump Instruction Manual
7. Reference card for CRD Chapter 2, 4

C. OBJECTIVES

1. Describe operation of hydraulic control unit
2. Describe components and operation of CRD Hydraulic System
3. Describe air systems needed for control rod scrams
4. Discuss the associated control room and local instrumentation
5. Review applicable Tech Specs

D. GENERAL DESCRIPTION

1. The CRD System controls changes of reactivity by incrementally positioning control rods within the core in response to Reactor Manual Control signals.
2. The system is also required to quickly shut down the reactor by rapidly inserting control rods into the core in response to a manual or automatic signal.
3. Control Rod Drive Hydraulic Control Unit
   a. One hydraulic control unit is provided for each control rod. Total of 185 HCUs.

b. Combines all operating valves and components needed for the normal positioning or scram of a single control rod.

c. Unit functions on pressures supplied by CRD Hydraulic System to insert or withdraw its associated drive and provide cooling water to the drive mechanism.

d. Provides stored energy to give initial scram energy to rod.

4. Control Rod Drive Hydraulic System

a. Purpose

CRD Hydraulic System provides the necessary pumps and valves to provide water at the proper pressure to the HCUs for all operations of control rod motion.

Piping Arrangements

b. Provides piping and necessary volume to ensure that all rods can scram yet prevent loss of an excessive amount of vessel inventory.

E. COMPONENT DESCRIPTIONS

1. Hydraulic Control Units (Fig. 1)

a. Purpose

Combines all operating valves and components required for the normal or scram operation of a single control rod.

b. Components

Hydraulic risers
Manifold and directional control valves
Scram inlet and outlet valves
Accumulator
Instrument assembly

c. Installation Configuration

1) Quantity 185
(one for each CRD)

2) Arrangement

Roughly equally divided into 4 banks of HCUs on each side of the reactor building at ground floor.

d. Piping Assembly (Fig. 2)

1) Seven hydraulic risers

Insert line - to CRD underpiston area

Cooling water - from cooling water header

Exhaust line - to CRD Hydraulic System return line

Scram discharge - to scram discharge volume

Drive water - from drive water header

Charging water - from charging header to accumulator

Withdraw line - to CRD overpiston area

2) Manifold

a) Purpose

Directs water between the seven risers and valves on the HCU

b) Components

Contains cooling and drive water check valves, filter elements to protect the directional control valves and the CRD and pressure test plugs.

3) Inlet and Outlet Scram Valves

a) Purpose

Control water flow to and from the CRD for scram insertion.

e. Driving Water Section (Fig. 2)

1) Components

Four normally deenergized solenoid operated directional control valves are mounted on the piping assembly manifold.

Solenoids powered by 120 vac bus.

e. 2) Directional Control Valves

Energized by the action of the Reactor Manual Control System to control pressure on the under and overpiston area of the associated CRD mechanism.

3) Operation

By energizing two of the four valves simultaneously, the drive water header is connected to either the under or overpiston area while the exhaust header is simultaneously connected to the opposite side of the drive piston.

a) Insert operation

Valves 85-40A and 85-40D open

Valve 85-40B opens to settle the drive

Valves 85-40A and 85-40D close

Valve 85-40B closes

b) Withdraw

Valves 85-40A and 85-40D open to lift drive off of the collet fingers

Valves 85-40A and 85-40D close

Valve 85-40D and 85-40C open

Valve 85-40C closes allowing drive to settle

Valve 85-40B closes

4) Flow Control Valves

Two of the directional control valves are equipped with integral flow control valves. These valves are arranged so that they pass flow to or from the underpiston area.

a) Insert throttle valve

Located with directional control valve porting flow to underpiston volume

Flow to underpiston volume is greater than exhaust from overpiston (because of larger underpiston area.)

Thus, better speed control obtained by throttling larger flow, i.e., underpiston flow.

Throttle drive water

b) Withdraw throttle valve

Located with directional control valve porting flow from underpiston line.

During withdraw, rod is falling; therefore, it is necessary to brake the rod by throttling flow from the underpiston area.

Flow from underpiston area is greater than to above piston (because of larger underpiston area.)

Therefore, speed control is only feasible on underpiston port.

In addition, full drive water pressure is needed to hold collet fingers extended.

If drive water were throttled, collet fingers could not be extended and rod movement would not be consistent.

Throttles exhaust water.

5) Flow Rate

Flow is approximately 4 GPM when the drive is being inserted at 3 inches per second and 2 GPM during drive withdrawal operation.

Remember that P-under/P-over areas are 4.0 in ^{2}/1.2 in ^{2}. Therefore it would seem that 2 GPM is an excessive flow rate. This high rate, however, is required to accommodate the higher P-over collet seal leakage. (P-under seal leakage is much smaller.)

6) Drive water and cooling water check valves

During a scram, the drive insert header is pressurized to accumulator pressure.

Back flow is prevented through the cooling water line by the cooling water check valve

Back flow through the drive header line is prevented by the drive water check valve since accumulator pressure could lift the drive water supply valve 85-40A off its seat.

NOTE: A check valve cannot be placed in exhaust header for the same purpose because it would prevent normal flow operation of the exhaust header. Valve 85-40B is oriented so that increased pressure tends to force the valve closed rather than than force it open.

7) Filters

Filters are provided in the drive water line to the directional control valves and in the drive insert and drive withdraw header to the CRD mechanism to prevent damage to the directional control valves and the drive mechanisms from rust or scale in the CRD Hydraulic System water (most of the supply piping is carbon steel.)

f. Cooling Water Section (Fig. 2)

1) Components

Consists of cooling water riser and cooling check valves

2) Flow Path

Cooling water flows from the cooling water header through the check valve to the drive insert line at all times when the rod is stationary.

3) Flow Rate

Flow .25-.33 GPM at about 20 psi above reactor pressure.

4) Check Valve

When a drive is in motion, pressure in the insert line is at drive pressure (260 psi > reactor pressure).

Therefore, the check valve will be closed to close off the flow of cooling water and prevent drive water from recirculating back to the CRD Hydraulic System.

g. Scram Section (Fig. 2)

1) Operation

a) Scram action

Two scram pilot valves are directly connected to the Reactor Protection System so that the inlet and outlet scram valves open in response to scram signals.

b) Inlet valve

When open, the inlet scram valve permits the scram accumulator to supply the initial energy to rapidly insert the control rod.

c) Outlet valve

The opening of the outlet scram valve permits water vented from the overpiston area of the CRD to exhaust to the scram discharge volume.

d) Scram pilot air valves (Fig. 2)

(1). Quantity

Two per HCU

(2) Type

3-way solenoid operated valves

(3) Power supply

Energized normally by 120 VAC Reactor Protection System power

(4) Normal position

When one or both are energized, they port air to scram valves

(5) Scram action

Both deenergize on scram to vent air from scram valve diaphragm.

e) Scram valves

(1) Type

Both glove valves with Teflon seats to minimize leakage

(2) Normal lineup

Both air operated valves normally held closed by air pressure from instrument air header

(3) Scram action

Open on internal spring pressure upon removal of control air pressure (scram

(4) Timing

Start to open within .15 seconds after pilot valves lose voltage

(5) Sequencing

Outlet valves open slightly faster to prevent buildup of high pressures in CRD (has stronger opening spring)

(6) Position indication

Both provided with spring mounted position switch. When both valves open, position switches cause blue rod scram signal on full core display on panel five

(7) Air pressure in the valves is maintained at 75 psig. Higher pressures would

(a) Cause deformation of the Teflon seats with resultant valve leakage

(b) Slightly increase scram times, particularly for the initial phase of rod movement.

(8) Scram inlet valve leakage

Can cause pressurization of the underpiston area and possibly slow rod insertion.

(9) Scram outlet valve leakage

Causes depressurization of the over-piston area. Cooling water pressure on the under piston area can cause the drive to drift in.

f) Scram accumulator and instrument block (Fig. 2)

(1) Purpose

Serves as independent source of stored energy to initiate scram insertion of the associated CRD.

(2) Description

Piston type accumulator connected to N_2 cylinder

(3) Piston

Piston serves as barrier between high pressure N_2 (source of stored energy) and the water used to initiate a control rod scram. Under normal conditions, the piston is in the full down location.

(4) Piston seal

Piston sealed by two Teflon seals and a rubber O-ring.

(5) Normal lineup

Accumulator continuously charged by CRD Hydraulic System charging water header.

(6) Check valve

Check valve prevents flow back to charging header from accumulator. Accumulators will retain charge for some time in the event of loss of pressure (pump trip) in charging water header.

(7) N_2 Source

N_2 cylinder precharged with gas from an external source.

(8) Overpressure protection

Rupture disc on instrument block bursts at 2000 psi to protect accumulator from overpressure.

(9) Monitoring

Continuously monitored for gas and water leakage

(a) Water leakage past accumulator piston seals

Float type magnetic reed level switch senses water in N_2 side. Alarms when 37 cc of water accumulates.

(b) N_2 pressure

Low pressure switch senses low gas pressure (940 to 970 psi)

(c) Alarms

Either will cause "Accumulator Trouble" alarm in control room (audible and visual) (amber light on full core display) on panel five.

(d) Operation Action

Operator must then go to local accumulator trouble panel to se if low pressure or water level switch tripped.

Local panel will have alarm button lit for HCU. Operator must push button. If light goes <u>OUT</u>, alarm is <u>water leakage</u>. If light stays on, alarm is low gas pressure.

(10) Nitrogen charging (Figs. 3 & 4)

(a) Nitrogen for accumulator charging is supplied by 2 accumulator nitrogen charging stations. One on each side of the reactor building near the banks of HCUs.

(b) Components (Fig. 3) in each charging station normally consists of

Nitrogen bottle
Bottle pressure regulator and pressure monitoring instrumentation
2 isolation valves
Safety valve
Vent valve
Flexible hose

(c) Gas pressure

Since gas expansion during initial charging results in low nitrogen temperature, the final accumulator precharge pressure must be set only when the temperature of the nitrogen in the accumulator has reached equalibrium (room temperature) .

Fig. 4 is used to determine the proper accumulator precharge gas pressure.

Reason for requiring a variable charging pressure is to assure that the piston in the accumulator is always full down during operation, thereby guaranteeing the required amount of water is available to scram the drive. Too high a pressure would prevent this.

If too low a N_2 pressure is used, the low pressure alarm will be tripped even when the cylinder piston is full down. Too low a pressure will affect scram times.

If accumulators are charged to a low pressure in high room temperature and the room temperature subsequently decreases, it isprobable that the low pressure alarm will be tripped.

(d) Accumulator charging procedures (Fig. 2) (See Browns Ferry Operating Instructions 85Step IIIG and Tech Manual GEI 92807A for details.)

(i) Close all HCU riser manual isolation valves, including charging water valve 85-588

(ii) Connect a flexible hose from valve 85-590 to the floor drain and slowly open valve 85-590 and drain the accumulator.

NOTE: All manual isolation valves should be closed rather than only valve 85-588 (in step 1) above because if the reactor scrams while valve is open, 85 - 85-590 is open.

(aa) Cooling water header pressure will be directly connected to valve 85-590

(bb) Reactor water at temperature and pressure would be ported to the drive P-under area through the ball check valve and could, if the ball check valve failed, blow back through the insert line and valve 85-590.

(iii) Verify that valve 85-229A is closed.

(iv) Slowly remove cap on P6 to bleed off the instrument block gas pressure.

(v) Connect gas charging line to P6.

(vi) Open valve 85-229A.

(vii) Fill accumulator to specified pressure, close valve 85-220A and recap P6.

(viii) Open valve 85-229A and reverify correct pressure.

(ix) Close valve 85-590

(x) Slowly open charging water valve 35-588 to push the rechanical piston to the bottom of the cylinder

(xi) Reopen all HCU riser manual isolation valves.

(11) Procedures for draining water from instrument block (See Fig. 2)

(a) Close valve (85-229A) on accumulator instrumentation block

(b) Slowly remove cap on plug P-6.

(c) Briefly crack open valve 85-229A to blow out moisture.

(d) Return valve 85-229A and plug P-6 to normal condition.

(e) Check N_2 for proper pressure and recharge if necessary.

(12) HCU isolation (See GEI -92807A for details.)

(a) Precautions

(i) Control rod whose HCU is to be isolated should be latched in the full-in position.

(ii) The HCU should not be isolated for extended periods when the reactor is in cold shutdown in order to prevent seal damage due to loss of cooling water.

(b) Procedure

(i) Fully close the isolation valve (85-612) in the insert riser

(ii) Fully close the isolation valves in the withdraw and charging water risers (85-615 85-588)

(iii) Open the accumulator drain valve to discharge the water from the accumulator 85-590 to the floor drain

(iv) Fully close the isolation valve in the scram pilot air line. At the scram test panel in the control room, deenergize the scram pilot air valves.

(v) Fully close the isolation valves in the scram discharge riser 85-617 the cooling water riser 85-596, drive water riser 85-593, and the exhaust water riser 85-600.

(vi) Electrically isolate the HCU from the Reactor Manual Control System.

(vii) Discharge the gas side of the accumulator.

(13) Electrical isolation of the HCU

(a) Prevents operation of directional solenoid valves

(b) Accomplished by removing the color coded amphenal connectors.

2. Control rod drive hydraulic system

a. Purpose

Provides water at the proper pressure to the HCUs for all types of control rod motion

b. Basic Flow Path (Fig. 5)

1) CST

2) Suction strainers

3) CRD hydraulic pumps

4) Drive water filters

5) Recirculation Pump Seal flushing water

6) Charging water header

7) Flow control station

8) Drive water pressure control station

9) Cooling water pressure control station

10) Return to reactor

11) Normal system flow is 78 GPM

c. Hydraulic Supply

1) System suction - condensate storage tank

2) Pumps

a) Type

Two 100% multistage centrifugal electric motor driven pumps

(1) Pump 1A is specific to Unit 1 while pump 1B is a swing pump that can be used for Unit 1 or Unit 2.

(a) 1A pump normally valved in 1B valved out.

b) Rating

76 GPM at 1500 psig (plus 20 GPM to minimum flow ~~time~~ line)

During a reactor scram, however, the pump will be required to deliver a total flow of 200 GPM at 1350 psig (maximum rating) in order to recharge the accumulator (179 GPM to system and 20 GPM to minimum flow line.)

c) Speed increaser

Constant speed mechanical speed increases provided between motor and pump.

d) Suction strainers

Provided to protect pump seals, etc.

e) Valving

Each pump is provided with a manual suction and discharge isolation valve.

Discharge valve is a stop check valve to prevent reverse flow in the idle pump.

The pumps have a motor operated valve in the common suction line which direct flow either to unit 1 or Unit 2

f) Minimum flow

(1) Purpose

A minimum flow line is included upstream of the discharge valve to prevent over-heating of the pump in case the discharge valve is inadvertently shut.

(2) Flow path

Minimum flow line is locked open and recirculates 20 GPM to CST through orifice when the pump is running

(3) Valve

Minimum flow valve is stop check to prevent backflow through the idle pump

g) Power source

4160 Vac motors, 1A - Unit Board 1C - 1B Shutdown Board A

h) Cooling

Cooling water is provided to the oil cooler and thrust bearing by the Raw Cooling Water System

i) Recirculation Pump Seal Purge

CRD flow (4GPM/Recirc pump orificed flow) is directed to each recirculation pump seal to flush tho during startup conditions. This flush keeps dirg of seal piping to increase seal life and to limit radioactive waste discharge

j) Pump test - a pump test line is provided

(1) Flow path - from pump discharge to return line

(2) Purpose - allows pump tests when balance of system is shut down

k) Seals

Operating pump maintains seal pressure on standy pump to prevent air from entering the seals of the standby pump if suction pressure to the running pump should drop below atmospheric.

3) Drive water filter

a) Piping arrangement

Two filters installed in parallel; one is usually on line, the other in standby.

b) Filter mesh

50 micron absolute (25 mincons nominal) filter prevents rust, scale, etc. from entering HCUs.

c) Alarm

Condition of filters monitored by dp indicating switch. Alarm in control room at 20 psid.

d) Type

Cartridge type filters can be vented, drained and cleaned and reused.

e) "Y" Strainer

"Y" strainer is provided downstream of filters to protect system against large particles if a filter cartidge should fail.

d. System Pressure Control

1) Accumulator charging line

a) Purpose

Supplies charging water to the HCU accumulators

b) Normal lineup

Accumulators "float" at pump discharge pressure

c) Check valve

If pumps fail, accumulators are held charged by check valve in charging line which prevents backflow of water from HCU to the CRD Hydraulic System

d) Runout protection

During a scram, the HCU accumulators will be fully discharged

The CRD pumps will try to recharge all the accumulators at once.

To prevent pump runout and probable tripping of the pump motor on over-current

(1) A restricting orifice is provided to limit the maximum rate of recharging to 179 GPM (maximum flow is with reactor at 0 psig).

(2) A throttle valve downstream of the restricting orifice is provided to provide additional throttling if required

NOTE: The accumulators cannot be recharged until the scram is reset (scram inlet and outlet valves closed) due to drive seal leakage being greater than pump capacity.

e) Charging water pressure - is independent of reactor vessel pressure

f) Caution

High accumulator pressures can cause very rapid acceleration of control rod and possible damage by deforming tubes or causing severe shock when drive hits stop piston at end of travel (can invert Belleville washers.)

Therefore, do not exceed 1510 psig charging water pressure (GE Design Engineering value).

2) Flow control station (Figs. 5, 6)

a) Purpose

To provide a method for automatically controlling system flow.

b) Valve arrangement

Two pneumatically operated valves in parallel

c) Valve lineup

One in operation, the other in standby

d) Control

Flow controlled by flow indicating controller in control room with the M/A Station in Automatic

(1) Manual Mode

Operator sets controller output. Hence, valve remains at a constant open value

(2) Automatic Mode

Operator sets flow setpoint. Flow feedback signal from venturi type flow element in line. Controller compares setpoint and flow signal and adjusts valve position to hold flow constant.

e) Detailed valve control (Fig. 6)

(1) Air supplies

Manual loading control air through pressure regulator
Auto loading control air through E/P unit
Motive air from positionor

(2) Local manual operation of flow control valve

(a) Position 3-way valve to provide manual control air to desired FCV positionor from the pressure regulating valve

(b) After verifying FCV operability, open manual isolation valves and position Flow Control valve as required by adjusting Pressure Regulating valve flow

(3) Remote automatic operation of flow control valve (Fig. 6)

(a) Locally position 3-way valves to provide auto loading control air to desired flow control valve from E/P unit.

(b) Locally position electrical selection switch to direct signal from flow indicating controller to desired E/P unit.

(c) After verifying operability, open FCV manual isolation valves and position valve as required.

f) Flow with flow control valve closed

(1) Flow rates

9 GPM with reactor at zero pressure

3 GPM with reactor at rated pressure

(2) Purpose

Following a scram, the flow through the charging water header will be 170 GPM. The flow control valve will therefore be fully closed trying to maintain 76 GPM.

Flow of 3-9 GPM is permitted to pass through the system and back to the reactor vessel to assure that the reactor vessel return nozzle does not heat up (up on a stoppage of flow) and subsequently rapidly cool down upon re-establishing normal system flow. This prevents thermal overstressing the RPV nozzle.

3) Drive water pressure control station (Fig. 5)

a) Purpose

To provide a method for adjusting the pressure of the water supply used to insert and withdraw control rods.

b) Pressure control valves

(1) One motor operated pressure control valve

(2) One manual throttle valve for adjustment of drive water pressure in the event of failure of the motor operated valve

(3) Operation

Valve is positioned to maintain drive water pressure at reactor pressure plus 250 psig (P_{Rx} + 250)

(4) Drive water header

Provides driving forces to each of the HCUs.

4) Cooling water pressure control station

a) Purpose

Provides water at an adjustable pressure above reactor pressure to maintain CRD temperature much less than rated reactor temperature to protect CRD mechanism seals. Normal temperature is 200°F.

b) Valve arrangement

Motor operated pressure control valve bypassed by manually operated pressure control valve.

c) CRD Instrumentation

Temoerature of the CRD mechanism is monitored by a thermocouple in the Rod Position Information System probe.

Temperature is printed out on a multi-poing recorder in the control room. A high temperature alarm alarms at 350°F on a control rod drive mechanism.

d) Purpose of temperature monitoring

(1) Operation at high temperatures for extended periods will reduce the life of the drive graphitor seals.

(2) Temperature instrumentation also provides a means for detection of leaking scram outlet valves.

e) Operation

Valve is positioned to maintain cooling water pressure at reactor pressure + 18 - 37 psig (P_{Rx} + 18-37)

f) Flow path

Cooling water from the cooling water header flows to the HCUs where it is ported to the drive insert line.

5) Automatic drive and cooling water header pressure control

a) Pressure in the drive and cooling water headers is dependent upon reactor pressure

b) The flow control valve maintains a constant flow of 78 GPM through the system. (That is, the flow control valve will have to open further as reactor pressure increases in order to maintain the required system flow.)

c) If flow stays constant in the system, the pressure drop across the drive and cooling water pressure control valves will stay constant regardless of reactor pressure.

d) As a result, the drive and cooling water pressure control valves will require adjusting only once (upon system startup) and will not require constant adjustment during a startup or shutdown.

6) System return line

a) Flow path

Returns water from the CRD Hydraulic System to reactor.

(1) Exhaust from cooling water PCV

(2) Exhaust from stabilizing valves

(3) Exhaust from HCUs

(4) Exhaust from test bypass line

b) Primary containment isolation

Primary containment isolation is provided by two check valves backup by a motor operated valve which has no automatic isolation signals

c) RPV nozzle

The flow returns to the reactor vessel through the CRD return nozzle.

d) Purpose of returning to reactor vessel

The CRD Hydraulic System must be operated on a constant differential pressure above reactor pressure.

Without returning to the RPV, the drive and cooling water pressure control valves would require continuous operator adjustment or automatic control to yield constant differential pressure.

7) Stabilizing valves

a) Purpose

To provide system flow stability when inserting or withdrawing a control rod drive.

b) Configuration

Two identical sets of valves

In each set, one valve is for insert operation, the other for withdraw operation.

c) Normal lineup

One set of valves in operation with the other valved out

Solenoid valves are open unless rod is driving.

d) Selector switch

Control room switch determines which set of valves is in service.

e) Flow adjustment

Needle valves downstream of each solenoid valve provided for setting the required flow.

f) Flow path

Path is provided from the drive water header to the return line.

g) Normal operation

Both solenoid valves in one set are normally open with flow set by throttling valves

Insert stabilizing valve - passes 4 GPM (flow required by a CRD while inserting.)

e. Scram Discharge Volume and Instrument Volume (Figs. 5 & 7)

1) Purpose

To receive and contain the water exhausted from all CRDs during a scram, thereby limiting the loss of water from the reactor vessel.

2) Definition

a) Scram discharge volume

The header piping that runs over the top of the HCUs.

It is the piping that connects the HCUs to the instrument volume.

b) Instrument volume

The "U" shaped piping provided for the measurement of water released from the drives to the scram discharge volume during a scram.

3) Scram discharge volume valves

a) Vent valves - 2 air to open, spring the close valves

b) Drain valve - 1 valve air to open, spring to close valve

4) Scram discharge volume sizing

Independent of the instrument volume, it is sized to contain the water volume discharged from all the CRDs (3.3 gals/drive).

Thus, during a scram, the scram discharge volume partially fills with water.

5) Scram action

On a scram signal, the vent and drain valves will shut.

6) Initial volume pressure during a scram

The back pressure in the volume will not exceed 65 psig initially so as not to affect drive scram timing.

7) Pressure rating after scram

With all CRDs fully inserted, leakage past the CRD seals from the CRD pump and from the reactor through the scram valves fills the discharge volume and pressurizes the volume to reactor pressure.

8) Overpressure protection

Relief valve set at 1250 psig.

9) Vent and drain path

The SDV vent and drain valves are piped to the Reactor Building Equipment Drain Tank (RBEDT), to assure no airborne activity is released to the reactor building atmosphere when a scram is reset.

10) Instrumentation volume

a) Provides means for measuring amount of water in DSV. Volume in instrument volume is not needed for scram.

b) Normal conditions

The scram discharge volume should normally be empty.

If excessive leakage or inadvertent vent or drain valve closure causes the scram discharge volume to fill, control rod insertion might be prevented during a scram.

c) Level switches

Six float type level switches are connected to the instrument volume to monitor the volume for abnormal water level.

d) Volume not drained switch

When 3 gallons accumulate in the instrument volume, one level switch trips and causes an alarm in the control room.

e) High level

When the instrument volume is half full (25 gallons) a second level switch trips and causes a rod block.

f) High-High level reactor scram

The other four level switches trip when the instrument volume is full (50 gallons).

When two switches in a one-of-two-twice logic trip, the reactor will scram since operation without scram capability is forbidden and scram capability is lost if the discharge volume fills further.

g) High-High level bypass

Discharge volume high water level scram can be bypassed using a keylock switch in the Shutdown and Refuel modes of operation.

a) This enables the Reactor Protection System to be reset so that the discharge volume vent and drain valves can be opened to drain the discharge volume after a scram without initiating a subsequent scram due to high water level.

b) When the SDV high water level scram is bypassed, control rod withdrawal is blocked and an alarm annunciates in the control room.

11) Scram dump valves (pilots and solenoids) (Fig. 7)

a) Purpose

These valves apply 75 psig control air to the diaphram operators of the SDV vent and drain valves to hold the valves open

b) Quantity

There are two total valves.

c) Power supply

Each solenoid is powered from a separate Reactor Protection System bus.

d) Scram action

When both solenoid operated scram dump valves are deenergized by the Reactor Protection System, air is vented to atmosphere and the SDV vent and drain valves shut.

f) Conditions for closing

If only one scram dump valve is deenergized, the SDV vent and drain valves will remain open.

12) Discharge volume isolation test valve

a) Purpose

Can be manually closed from the control room to check for leaking scram outlet valves.

b) Power supply

Normal power supply instrument and control BusA back up power supply is the uninterruptable 120 VacBus

13) Scram pilot solenoid valves

a) Purpose

The diaphram operators of the scram inlet and outlet valves are held closed by instrument air at 75 psig.

b) Quantity

There is a pair of valves for each of the 185 HCUs.

c) Power supply

Each solenoid is powered from a separate Reactor Protection System bus.

d) Scram action

When both solenoid operated scram pilot solenoids are deenergized by the Reactor Protection System, air is vented to atmosphere and the scram inlet and discharge valves are opened by internal spring pressure resulting in the drive scramming.

e) Conditions for closing

If only one scram pilot valve is deenergized, the scram valves will remain closed.

14) Backup scram valves

a) Purpose

Provide redundant means of venting air from scram pilot valves and scram dump valves.

Primary purpose is to provide another mechanism for scramming the 1 or 2 drives which, due to unknown factors, fail to scram.

The valves are not intended to function as an alternate method of rapidly scramming the reactor.

b) Valves

Two solenoid operated three-way pilot valves normally deenergized.

c) Power supply

Powered from 125 vdc bus.

d) Scram operation

Both Reactor Protection System channels must trip in order to energize either of the valves.

Energizing <u>either</u> valve will vent air off all scram valves and the two scram dump valves.

Scram operation will be slow (15-20 secs) because of the large volume of air which must be vented through the small valve ports.

e) Backup scram valve action

The SDV vent and drain valves will also close if either one of the 125 vdc scram backup valves becomes energized. These valves are normally deenergized.

If either energizes, air is vented off the entire scram air header, opening HCU scram valves and shutting the shutting the SDV vent and drain valves.

f) Check valve around downstream B/U scram valve is to allow faster venting of air if only upstream valve energizes.

F. INSTRUMENTATION

1. Control Room Instrumentation

Item	Device	Range
System flow indicating Controller	--	0-100 GPM
Charging water pressure	Indicator	0-2000 psig
Drive water flow	Indicator	0-6 GPM
Drive water differential pressure	Indicator	0-305 psid
Cooling water flow	Indicator	0-80 GPM
Cooling water differential pressure	Indicator	0-60 psid
Return water flow	Indicator	0-50 GPM
Drive temperature (on back panel)	Multipoint Recorder	0-400 ^{o}F

2. Significant Alarms, Interlocks & Trips

Item	Set Point	Remarks
Scram valve air supply low pressure	70 psig	Alarm only. Indicates abnormally low control air pressure
Scram discharge volume not drained	3 gals.	Alarm function only. Indicates possible leaking scram outlet valve.
Scram discharge volume hi level rod block	25 gals.	Probable significant leakage. Provides a rod withdrawal block Reactor will scram at next higher level if not corrected.
Scram discharge volume Channel A/B high level	50 gals.	Above this level, adequate space for water coming from the drives upon a scram cannot be guaranteed Therefore, the plant must be scrammed.
Rod drive pump low suction pressure	18" Hg. absolute	Indicate of faulty suction path to pumps - probably a dirty suction strainer. Will trip the pump.
Accumulator high level/ low pressure	37 cc of water or 970 psig	Indicative of leaking nitrogen fitting, or leaking piston seals in accumulator cylinder or a reactor scram (causing low accumulator pressure). Two trips cause a rod out block.
Rod drive high temperature	350°F	Alarm only. Check cooling water flow to affected drive.
Charging water low pressure	1410 psig	Alarm only. Low accumulator pressure may result in longer scram times.
Rod Drive water filter high DP	20 psid	Alarm only. Indicative of a dirty filter. Valve in standby filter.

3. Significant Local Instrumentation

   CRD pump suction pressure

   Filter differential pressure

   System flow

   Charging water pressure

   Drive water flow

   Drive water differential pressure

   Cooling water flow

   Cooling water differential pressure

   Stabilizing valve flow

   Return water flow

   Scram valve instrument air pressure

   Accumulator nitrogen pressure (on HCU)

G. OPERATIONAL SUMMARY

1. Keep running at all times:

   a. Prevents damage to seals by providing cooling water for the CRD mechanism.

   b. Provides flow through CRD mechanism to vessel, preventing 'crud' from falling from vessel into CRD mechanism, possibly fouling filters or damaging seals.

   c. Keeps system filled and vented.

   d. Keeps recirculation system pump seals purged.

2. Venting

   a. The CRD Hydraulic System should be well vented prior to starting CRD pumps to prevent pressure surges (water hammer) in the CRD System lines.

   b. The pressure overpiston and pressure underpiston lines should be well vented to insure proper control rod drive operation.

c. Causes of air in system

1) Occurs primarily when reactor is at zero pressure and CRD pumps are off.

2) Following removal or reinstallation of a CRD mechanism.

3) Following hydraulic control unit (HCU) servicing.

d. Vent locations

1) CRD Hydraulic System

Pump vents

Filter vents

Piping high point vent valves

2) CRD pressure overpiston piping

CRD pressure underpiston piping

Plug type vents located in high point on piping. No hard piping installed, hoses must be run from vent plugs to floor drains.

e. Problems of air in CRD pressure overpiston lines

1) Erratic rod response to control occurs

2) Rod may not settle fully - an "accumulator discharge effect" occurs.

f. Problems with air in CRD pressure underpiston line

1) The CRD will fail to notch out because of a loss of unlatching d/p.

2) The CRD will fail to notch in because insufficient d/p will be produced to move the rod to the next latched position. It will have a long settling time as it settles back to its original position.

3. Scram Valve Leakage

   a. If scram valves leak, a d/p will be caused across the piston resulting in slow rod insertion

   b. This will be seen as "rod drift".

   c. To clear the condition, insert the rod fully and scram the control rod to try to get scram valves to reseat.

4. Cooling Water Pressure High

   a. If cooling water pressure is increased to a point where the d/p is enough to lift the control rod, slow inward movement of the control rods will occur.

5. CRD. Drive Pressure Variations

   a. The drive water pressure of P_{Rx} x +260 psig is a nominal value.

   b. Due to variations of the CRD mechanism seals, i.e., different wear rates, etc., more than 260 psid might be required to move a rod.

   c. If a rod does not move with drive water pressure set at reactor pressure +260 psi, increase the drive water pressure until the rod begins to more.

   d. Then decrease pressure to nominal to keep rod moving.

   e. This often occurs after the rod is withdrawn for the first time after a long outage.

6. Scram

   a. Following a scram but before the scram discharge volume is full, the control rod will be in an overtravel in position since there is still a large d/p across the piston.

   b. Therefore, the green full in light on panel five will be on but there will be no rod position readout displayed.

   c. After the scram discharge volume is full, there will be no d/p across the piston, and the rod will settle into the 00 piston.
   position

7. Failure of CRD pumps

   a. Operator will be unable to move control rods using normal procedures

   b. Failure of both CRD pumps can be tolerated for a short time.

   c. Accumulators will start discharging because of back leakage through check valves.

   d. If there is low pressure on an accumulator, plant should be scrammed if reactor pressure is <550 psig.

H. RELATIONSHIPS WITH OTHER SYSTEMS

1. Raw Cooling Water

   CRD Hydraulic System pumps cooled by Raw Cooling Water System. Therefore, Raw Cooling Water must be operating in order to operate CRD System.

2. Power Supply

   1A pump is powered from 1 C 4160 Unit Board; 1B is powered from Shutdown Board 1A which can be fed from a diesel - needed to prevent damage to CRD mechanism seals by providing cooling during loss of normal power conditions.

3. Reactor Protection System

   Provides signals to energize or deenergize scram pilot and dump valves and backup scram valves.

4. Reactor Manual Control System

   Provides signals to hydraulic control unit to control directional control valve positions to control normal rod motion.

5. Control Air System

   Services the flow control valves, scram valves and scram discharge volume vent and drain valves.

6. Recirculation System Pump Seal Purge

   CRD flow is directed to both seals to purge the seals of contaminates which would cut the seals and possibly increase Rad waste activity

7. Contaminated Condensate Storage Tank

   Provides water for the system

I. TECHNICAL SPECIFICATIONS

1. See Control Rod Drive Lesson Plan for all applicable technical specifications associated with the control rod drive hydraulic system.